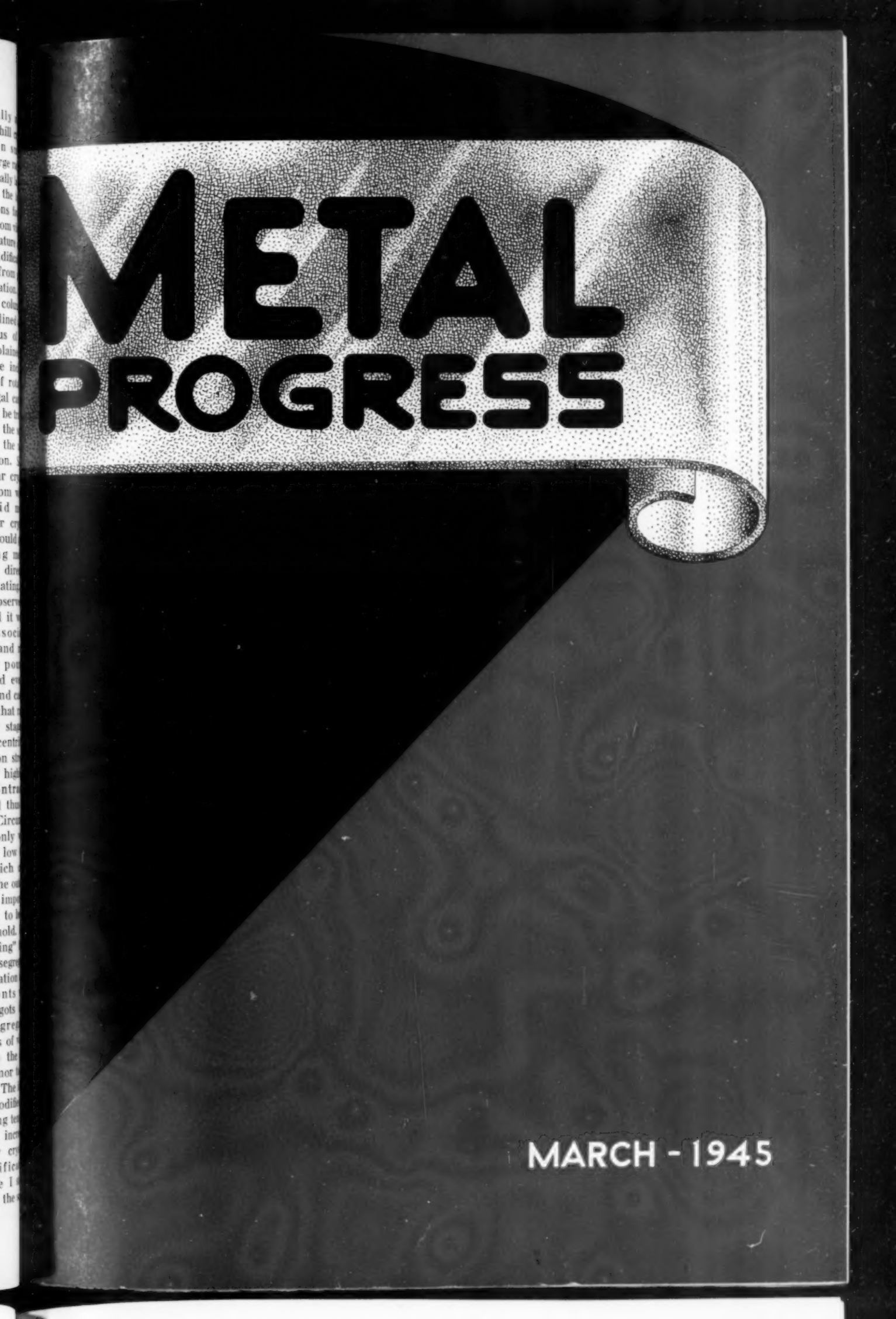
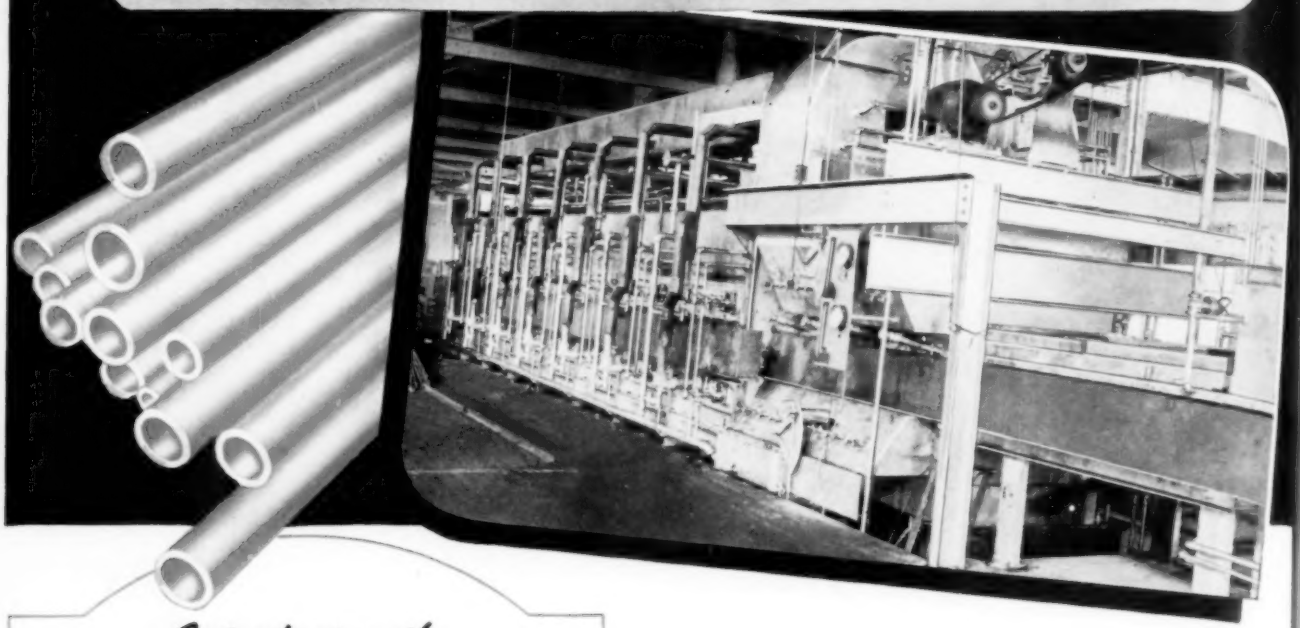

METAL
PROGRESS
MARCH - 1945

Bright Normalizing and Annealing of Tubing

and the development of the

SUPER-FAST GAS QUENCH



Introducing the

SUPER-FAST GAS QUENCH

Surface's background and knowledge of controlled atmospheres and convection cooling made possible the development of the super-fast gas quench for welded aircraft tubing X-4130. Of most importance, this development made possible the use of welded aircraft tubing which heretofore had limited use in aircraft construction.

Bright normalizing and annealing together with the super-fast gas quench will find other applications of equal importance to postwar production. Consult Surface Engineers on problems that you may have.

● Every foot of aircraft tubing is inspected immediat after the final anneal or normalizing heat treatment. T would be impossible if scale or oxide were present the surface of the tube. Therefore it must be bright n malized or annealed.

The first Surface Combustion Bright Normalizing a Annealing unit was installed in 1934 and since that ti there have been more than 30 units placed in operati in tubing plants. These are of the radiant tube, rol hearth type utilizing DX prepared atmospheres to prev scale or oxide on the metal surface. The importance this development to the war effort is indicated by the f that 24 of the total units installed were made since 19

The Heat Treater's Helping Hand

Surface

SURFACE COMBUSTION • TOLEDO 1, OHIO

Standard and Special Industrial Furnace Equipment for Forging, Normalizing, Annealing, Hardening, Drawing, Carburizing, Nitriding and Heating. Special Atmosphere Generators. *Write for bulletins.*

METAL PROGRESS

Vol. 47 **March, 1945** **No. 3**

Table of Contents

Notes About Some Steel Cartridge Cases Made in Germany 491

Stress-Corrosion Tests of Bridge Cable Wires 496
by Rolla E. Pollard; Abstract of Research Paper 1604, National Bureau of Standards, Sept. 1944

Selection of Bar Steel Used As-Rolled or Drawn 497
by John H. Frye

Preparation of Ultra-Pure Cartridge Brass 505
by J. L. Rodda and Gerald Edmunds

Bits and Pieces 508-510

Quenching Oils 508
by Petroleumensis

Lead Foil as Base for Next to Last Step in Metallographic Polishing 508
by J. B. Cohen and J. H. Maker

Mounts for Fine Wire and Thin Sheet 509
by C. G. zur Horst

Why Did It Sprout? 509
by John B. Zappone

Brazing Keys Into Shafting 510
by T. L. Burkland

Identification of Nickel Alloys by Spot Tests 510
by W. A. Mudge

Mechanical Properties and Weldability of High Strength Plate . . 511
by George F. Comstock

Arc Welding Troubles and Their Cures 520-B
by Westinghouse Electric & Mfg. Co.; Data Sheet No. 2

Metals for Railroads 521-536

How Rail Failures Are Being Prevented 521
by R. E. Cramer

Detection and Prevention of Incipient Cracking in Firebox and Boiler Steel 524
by Ray McBrian

Metal Limitations in the Perfection of Motive Power . . 527
by Paul L. Irwin

Improving the Railroad Axle 529
by O. J. Horger

The Railroad Car Journal Bearing 532
by John R. Jackson

Some Effects of the Trend Toward Rolling Stock of Lighter Weight 534
by Stephen H. Badgett

Personal Items 538, 540

Literature From Advertisers, Free to Readers . . . . . 546, e.s.

Advertising Index 630

Editor
Ernest E. Thum

Advisory Board
Ray T. Bayless
R. C. Dalzell
H. L. Edsall
W. H. Eisenman
C. H. Herty, Jr.
Zay Jeffries
C. D. King
C. H. Stevenson
C. E. Swartz
F. G. Tatnall
Kent R. Van Horn

Copyright, 1945, by AMERICAN SOCIETY for METALS, 7301 Euclid Ave., Cleveland, Ohio. Published monthly; subscription $5 a year in U. S. and Canada. Current copies $1; special reference issues $2. Entered as second-class matter, Feb. 7, 1921, at the post office at Cleveland, under the Act of March 3, 1879. . . . . The American Society for Metals is not responsible for statements or opinions printed in this publication. The Editor is sponsor for unsigned and staff articles. . . . . Requests for change in address should include *old* address of the subscriber.

Measuring enamel thickness with an electric gauge.

TI-NAMEL

Another New Creation by Inland Steel Company's Research Laboratories

The long awaited porcelain enameling base, which eliminates the necessity for a ground coat, is here! It is Ti-Namel, the new titanium alloy steel—the newest creation by Inland's research laboratories.

Ti-Namel is superior in every respect to older types of base metals. Its drawing properties are equal to the best deep-drawing steels. It does not age strain no matter how long it remains in storage before fabrication. Inland Ti-Namel Steel does not reboil. Therefore vitreous enamel finishes, equal to the best multi-coat ware, are obtained with white or color coat enamels applied direct to the base metal. This results in a thinner coat which reduces chipping hazards and increases the service-life of the ware.

Ti-Namel reduces reoperations, edging, and scrap. It is fired at lower temperatures, and in less time. In short, Inland Ti-Namel Steel increases shop output, lowers manufacturing cost, and assures superior vitreous enameled ware.

Pending patent applications on the new enameling process and product made thereby, are owned jointly by Inland Steel Company and The Titanium Alloy Manufacturing Company under trust agreement.

Write for copy of the Ti-Namel Bulletin and licensing agreement. Inland Steel Company, 38 South Dearborn Street, Chicago 3, Illinois. Sales Offices: Cincinnati, Detroit, Kansas City, Milwaukee, New York, St. Louis, St. Paul.

INLAND STEEL

NOTES ABOUT SOME STEEL CARTRIDGE CASES MADE IN GERMANY

THIS BRIEF REPORT about German cartridge cases made of steel will not discuss how a metal cartridge works in the gun during and after firing, and why brass is more satisfactory than steel, but will merely attempt to describe briefly some steel cases made and used by our enemy, and studied by American metallurgists. There is no information available for publication as to maximum and minimum tolerances on cartridges, complete rounds, or breech mechanisms of the guns in which they were to be used, nor of the firing history (number of stoppages from stickers), but it is only reasonable to conclude that the German military men would accept no product as early as 1934 that could not be manufactured in quantity or could not be used in the field with success.

Composite Cases for Larger Calibers — All the cartridges of recent manufacture for moderate calibers are one-piece and could readily be drawn from plain or winged disks, in a manner quite analogous to the manufacture of brass cases, with the exception of a stubby case for a 105-mm. howitzer which was made in four pieces. This will be described at the outset, since it is similar to the multi-piece cases for 77-mm. field guns used by the Germans during the latter years of the first World War, and allied to many experimental designs investigated by the American Ordnance Department some four or five years ago.

The accompanying sketch, Fig. 1, shows schematically the old German 77-mm. cases. At least five varieties were used, all utilizing an oversized brass rivet at the center of the base, this rivet being countersunk with a recess for the primer. Variety *A* (Fig. 1) is a brass cup with thin base riveted to a round steel plate acting also as an extractor ring. Variety *B* (not sketched) was the same except that the cup was also of steel, spot welded to the base plate. Variety *C* (shown in Fig. 1) was much the same as *B* with the addition of a short, tight-fitting brass cup lining its bottom, inside. In variety *D* (Fig. 1) the shell was pressed into a machined steel ring; examples were found where the shell was of brass, others were of steel. These cases were a little over 9 in. long, the steel walls were 0.030 in. thick at the mouth and 0.045 in. thick at the base. Chemical analysis indicated a medium hard

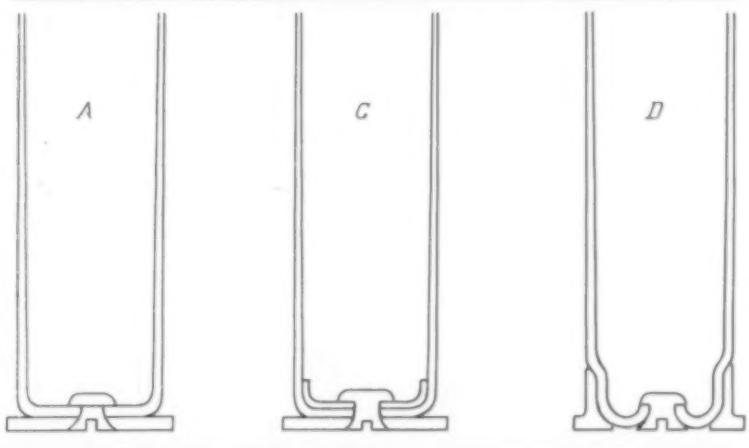
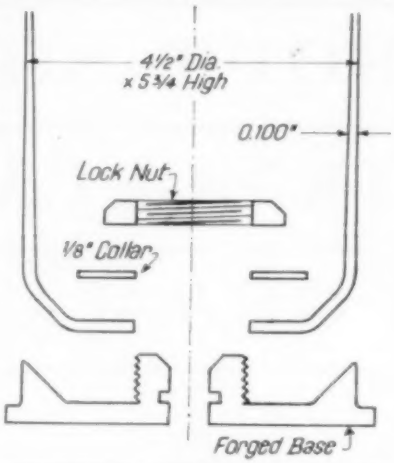


Fig. 1 — Sketch of Multi-Piece Construction of 1918 German Cartridges for 77-Mm. Field Gun, With Steel or Brass Skirt, Steel Plate or Ring for Base, and Brass Rivet for Primer Socket and Passages

Fig. 2 — Exploded Sketch of Four-Piece Steel Case for 105-Mm. Howitzer, Made in Germany in 1937



steel: 0.35% carbon, 0.25% silicon, 0.80% manganese.

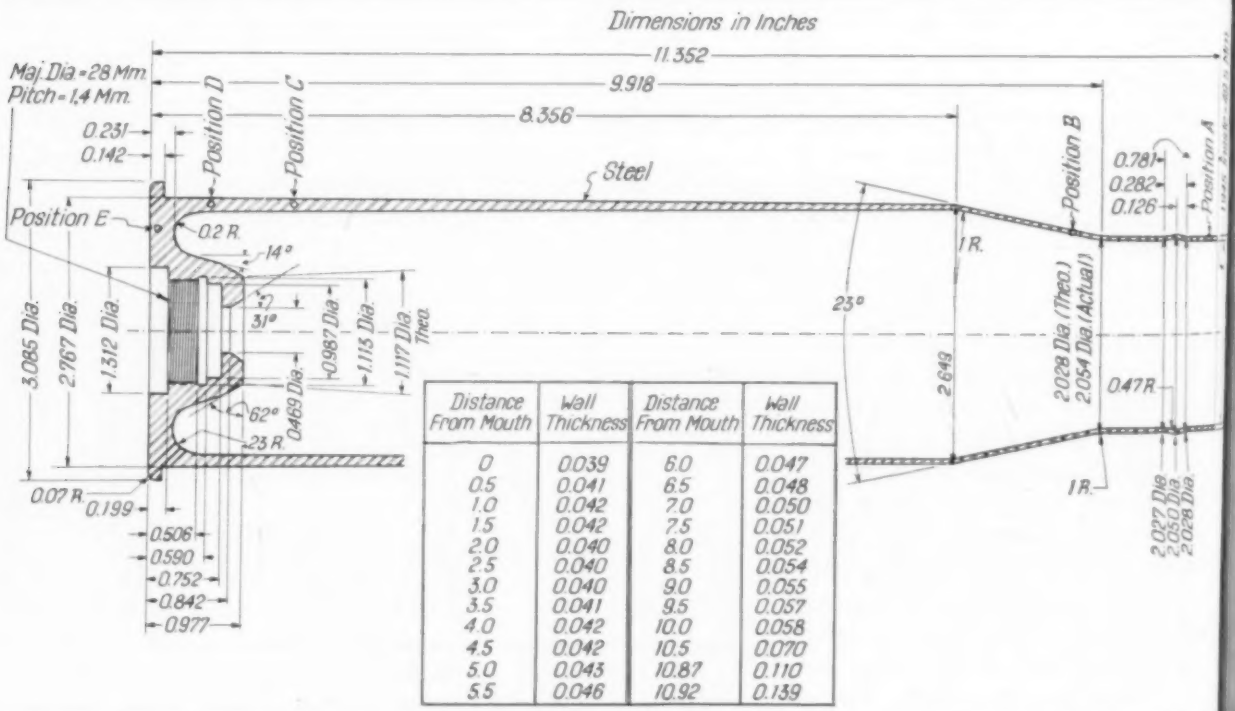
(In passing it might be mentioned that the Germans were making in 1918 a cartridge for a 0.30-in. caliber rifle, drawn of copper-coated, 0.15% carbon steel. Its hardness in the sidewall near the base was about 180 (Vickers 10-kg.). The copper coating varied from 0.0006 to 0.0025 in. thick on the outside and 0.0008 to 0.0011 in. inside.)

Some elements of the old design (variety *D* of Fig. 1) can be seen in the 1937 German case for 105-mm. howitzer. An exploded view of this four-piece assembly is shown in Fig. 2. The shell is very short, being only about 5¾ in. high and 4½ in. diameter; it was evidently cold drawn from a disk of 1010 steel (C 0.10%, Mn 0.42%, Si 0.08%, Cu 0.10%) in pearlitic condition. No mouth anneal was necessary. The base was machined of a 1040 upset forging. A waxy substance was used for a seal at the joints. All parts had a thin brass coating all over.

The original properties of the steel plate from which the cup was drawn, as judged from a sample cut from the head were 48,000 psi. yield at 0.1% offset, 13% elongation in 2 in. and 133 Vickers hardness.

The corresponding physical properties for the case's cylindrical drawn sidewall near the head were 98,000 ultimate strength, 78,000 yield strength at 0.1% offset, 4% elongation and 2[illegible] Vickers hardness. These are very low tensile and hardness values, in view of American ideas of what is necessary to avoid permanent expansion at the moment of firing, resulting in a "sticker", or at least a shell that can be extracted only with difficulty.

One-piece cartridges of steel have been used by Germans in quantity in all sizes from small ones for 0.20-mm. Mauser and Oerlikon guns to 210-mm. mortars, the latter being larger than any fixed ammunition used by the U. S. Army. About 20 samples of 50-mm. cases, captured at various times and places, were studied at Frankford Arsenal. A scaled drawing of one is shown in Fig. 3, photographs at about ¾ size of bases and sides of a typical sample in Fig. 4, macro-etched



Distance From Mouth	Wall Thickness	Distance From Mouth	Wall Thickness
0	0.039	6.0	0.047
0.5	0.041	6.5	0.048
1.0	0.042	7.0	0.050
1.5	0.042	7.5	0.051
2.0	0.040	8.0	0.052
2.5	0.040	8.5	0.054
3.0	0.040	9.0	0.055
3.5	0.041	9.5	0.057
4.0	0.042	10.0	0.058
4.5	0.042	10.5	0.070
5.0	0.043	10.87	0.110
5.5	0.046	10.92	0.139

Fig. 3 — Dimensions of Typical 50-Mm. German Steel Cartridge, 1940 Manufacture

base section magnified two diameters in Fig. 5 (page 494), and typical microstructures at standard positions in Fig. 6.

50-Mm. **Tank-Gun Ammunition** — Summarizing the numerous reports on 50-mm. steel-cased ammunition, we find the date of manufacture to be 1940 to 1942. Most of it was fitted with armor piercing shot and designed for use by tank guns. All of it is made of a composition falling within the chemical specifications of W.D. 1010; manganese is around 0.40%, silicon around 0.10%, nickel, chromium and molybdenum at a few hundredths only. Most of the analyses show more than what would be incidental copper in American practice, some going as high as 0.15% Cu, apparently an intentional addition (perhaps to improve atmospheric corrosion resistance), since the low residuals of other common alloying elements indicate manufacture from blast furnace iron or very carefully segregated scrap. The early steels were aluminum-killed; later there is enough titanium appearing in the analysis to indicate its intentional use as a deoxidizer and to control grain size to 7 or 8. Inasmuch as miniature impact pieces cut from heavily worked sidewalls show good toughness it is probable that the metal is of a "non-strain-aging type" which retains its toughness after cold work and aging.

Original condition of the disk was sometimes pearlitic (as rolled) but more often partially spheroidized. This is inferred from the observed microstructure at the base, position E, Fig. 3 and 6, where little or no cold work has been done. (An exception is one sample of extra long cartridge case — 15.2 in. long — which was made from a completely spheroidized disk.) Some designs having a massive primer pocket were probably made from a pre-formed disk, although most of them were doubtless cupped and drawn from a plain disk according to conventional practice. The contours between base and inside sidewall are usually smooth and unscratched by punch marks; deep

Fig. 4 — Base and Side Views of Typical 50-Mm. Steel Cartridges. Surface appearance would hardly be acceptable to American inspectors

etched cross-sections such as Fig. 5 show no folds in the structure, indicating that careful press work and die design have avoided this common defect. The extraction flange is formed by bumping and flowing metal sideways in the base, after which the base is machined flat. Since the micros in Fig. 6 show the carbides in the sidewalls to be completely spheroidized, even though the blank had some pearlite at the start, it is probable that the anneals between drawing operations were in the neighborhood of 1250° F.; possibly a final strain relief at about 900° F. was also given the

were electroplated, inside and out, with brass 70:30 or 80:20 composition. Some were given preliminary copper flash. The inside plating required a conforming electrode; thicknesses range from 0.15 to 0.3 mil, but all the coatings are porous they afford little real protection to rust atmosphere. Inside coatings, however, are much to prevent sparking during loading operations as to prevent reaction between metal and propellant.

These shells, for what may be called small caliber artillery, are fairly representative of

Fig. 5 — Macrostructure (Twice Size) of Base Section, 50-Mm. Steel Cartridge, Shows Flow Lines Characteristic of Carefully Designed Sequence of Pressing Tools and Drawing Dies

cases. The last cold draw was enough to boost the strength and hardness of the metal in the sidewall 1 in. above the base to the following values:

Properties of Steel Sidewalls, 1 In. Above Base, 50-Mm. Caliber

	Average	Range
Ultimate strength	103,000 psi.	95,400 to 110,000 psi.
0.1% yield point★	79,000 psi.	75,000 to 87,000 psi.
Elongation in 2 in.	3.7%	3.3 to 4.3%
Vickers hardness	198	190 to 210

★Compare this with early American experience which indicated that steel cases with a yield of 85,000 to 90,000 gave a prohibitive number of "stickers", whereas cases with yields of 115,000 psi. extracted easily.

Cartridges of this sort are necked to a considerable degree and have a small mouth; the mouth end is therefore annealed so it can readily be crimped around the projectile. Hardness at this end is 160 to 180 (Vickers 15-kg.).

As to protection, all these 50-mm. cartridges

man practice for both larger and smaller calibers

20-Mm. Steel Cases — Eight different captures of 0.20-mm. ammunition have also been studied much of it for Mauser and Oerlikon guns. The tendency is to use steel with somewhat higher carbon content; 0.15% carbon is common, sometimes 0.20% is noted. One analysis of a Mauser cartridge made in 1940 shows

Carbon	0.20%
Manganese	0.47%
Silicon	0.20%
Nickel	0.10%
Chromium	0.05%
Copper	0.17%

Some of these designs require extra heavy metal in the base, up to 0.60 in. Cupping of such a thick disk would be so difficult it is likely that a cold extrusion process was used. This is suggested by the lack of flow lines characteristic of hot forged pieces on an etched cross-section, and by the hardness near the primer cavity.

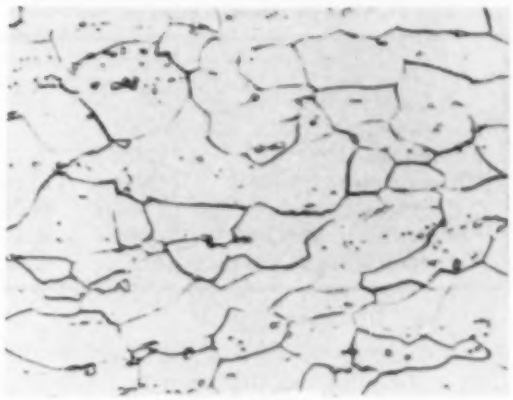
Despite the higher carbon in the steels, many of the cartridges were made of partly spheroidized disks. A wide variety of manufacturing routines

were evidently followed. Most cartridges were mouth annealed to 160 Vickers, but two samples were not mouth annealed, measuring 200 Vickers at the end. Maximum hardness of sidewalls, near the annealed mouth, went as high as 241, although 200 to 210 for the wall mid-length and near the base is more nearly representative. (This is 15 to 20 units lower than desired in American 20-mm. steel ammunition.) Corresponding tensile properties for 205 hardness are 95,000 psi. ultimate and 80,000 psi. yield (at 0.1% extension). The yield point in the metal in the wall is therefore just about what it is in the average 50-mm. case quoted in a previous paragraph.

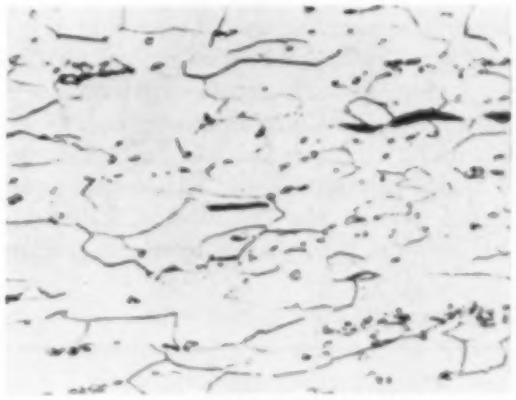
However, the above figures do not seem to be rigid requirements. An Oerlikon cartridge, for example, made in 1940 of a 1020 spheroidized steel disk, evidently received a very high stress relief anneal, because the ferrite grains in the heavily cold worked sidewalls were equi-axed. This cartridge had low hardness of 160 at the mouth, 185 in the sidewall near the base, and 185 in the base.

Much better protective coatings exist on these cartridges, as compared to the brass plating on the 50-mm. Some were made of disks copper coated on both sides. Others were given a phosphate treatment and dip coated with lacquer, 0.2 mil thick. Others were coated with a thermosetting resin. A report on German ordnance by the War Metallurgy Committee, published in *Metal Progress* last month, suggests that the elimination of brass coatings was a measure designed to save the last ounce of copper. As a matter of fact, the phosphatic and lacquer coatings do a better job of corrosion protection, as judged by the exterior condition of the steel cases when they reached American laboratories.

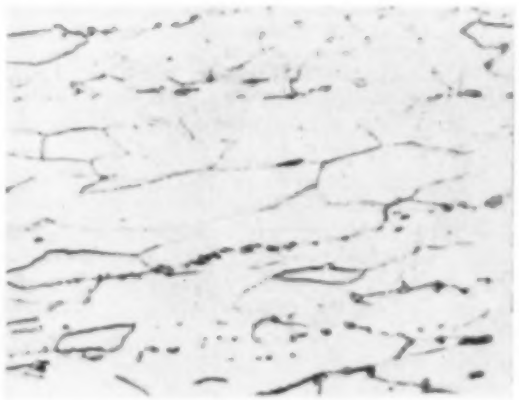
One-Piece Cases for Larger Calibers — Larger caliber shells, for example, 75-mm. (28 in. long) and 88-mm., were made from 0.10% carbon steel, evidently soft enough so a pearlitic blank, either as-rolled or normalized, could



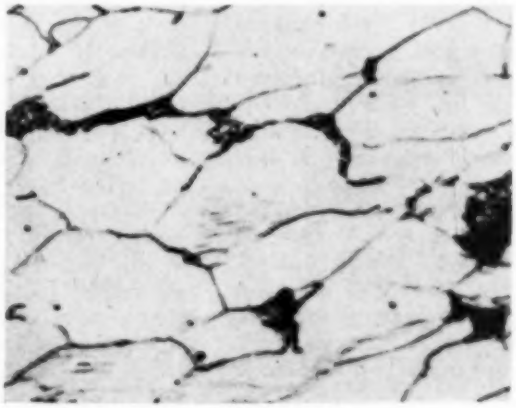
Mouth; Position A



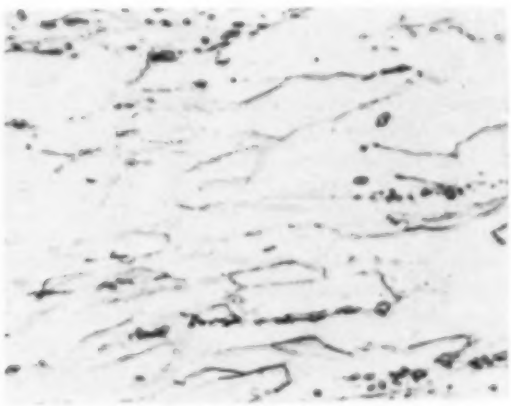
Position B



Position C



Base; Position E



Position D

Fig. 6 — Typical Microstructures of German 50-Mm. Steel Cartridge Case. Completely spheroidized carbides in cold worked walls; pearlite in base where deformation has been moderate. Positions located in Fig. 3

Properties of Steel Case for 210-Mm. Mortar Ammunition

	Mouth	Sidewall, Below Mouth			Base
		4 In.	11 In.	14 In.	
Thickness, in.	0.061	..	0.110	0.150	0.75
Ultimate strength, psi.	118,000	113,000	111,000	108,000	72,000
0.1% yield, psi.	107,000	94,000	81,000	86,000	68,000
Elongation in 2 in., %	4.7	5.1	4.6	5.4	15.0
Vickers hardness (30 kg.)	232	234	227	220	160

be used. Deep etching of the cross-section showed that metal had usually been "gathered" along the curved junction between base and sidewall, a matter condemned by some American ordnance officers because of their belief that it is the cause of "head splits" when such ammunition is fired.

The 88-mm. steel cartridge is somewhat thinner in the wall, especially near the base, than its brass counterpart — a fact of some interest. Physical properties and hardnesses are much like those quoted for the 50-mm. cartridge, a little higher than the average, although the small difference may not be significant. These cartridges were also brass plated, inside and out.

Finally, some notes on the 210-mm. mortar shell will be interesting. This is 16⅛ in. long, and was made of a spheroidized steel disk, ¾ in. thick, of 1015 basic steel, silicon killed. It was plated inside and out with 0.2 mil of 70:30 brass. It was made in 1941. Test pieces cut from it gave the results tabulated at left, above.

In conclusion, it may be stated that the Germans, faced with a serious shortage of cartridge brass, had started at least 10 years ago to make fixed ammunition with steel cases, and by 1940 had developed the manufacturing technique to where steel-cased ammunition from smallest to largest calibers could be made in very large quantities and used by troops in combat interchangeably with such of the older brass-cased ammunition as was available.

STRESS-CORROSION TESTS OF BRIDGE CABLE WIRE*

COLD DRAWN BRIDGE WIRE was installed in the General Grant bridge at Portsmouth, Ohio, in 1927, but had to be replaced some 12 years later because a number of breaks were discovered, most of them at the anchorage shoes. This wire was manufactured of high carbon steel and by methods such as those commonly used for this well-known material of construction with the exception that the wire was bare, not galvanized. They were replaced by cables spun of galvanized wire.

Some studies made at Carnegie Institute of Technology of the dismantled wire indicated that the wire, where not corroded, should be satisfactory for this service.

Of the corroded specimens examined, only those at the anchorage shoes seem dangerously brittle. At these locations, the wire appears to have been subjected to a combination of stress and corrosion, resulting in stress-corrosion cracks. Specimens from other locations, in spite of corrosion, seem as yet to have suffered no important deterioration in mechanical properties. The studies at the Bureau of Standards endeavored to produce experimentally the same type of fractures (thought to be caused by "stress corrosion") that occurred in service. These breaks were without "necking"; the fractured surface was diagonal in one or both directions at an acute angle with the length of the wire, but ended at both ends in a short square break. All of the cracks observed in the bridge occurred in the concave side of the curvature of the wire. This side would be under tension if the wire were straightened out in a cable, since the wire "lay dead" at a curvature of 10 to 12½ in., a curvature due to internal stresses and strains set up in reeling the wire. A few comparative tests were also made on samples of the heat treated wire taken from the dismantled Mt. Hope bridge, not only with its original zinc coating, but also after this had been stripped off to expose bare steel.

Specimens of the several bridge cable wire materials were statically stressed by changing the curvature of the wire. In most cases the 24-in. long specimens were bent to smaller radii calculated to produce stresses of given magnitudes and held in that position by tying their ends together with a bow-string; the center of the curvature was dipped into the corroding medium. The Portsmouth wire would be subjected to extreme fiber stresses exceeding 200,000 psi. merely by straightening. Accordingly, some specimens of this wire were constrained in a straight position by attaching the ends to a piece of wood, the middle one-third of which had been partially cut away as illustrated in Fig. 5. The ends were protected by molten tar.

Tests were made in distilled water and in various solutions. While the latter had salts in considerably higher concentration than occur in rain water, such solutions could easily be formed from rain water due to partial evaporation of water seeping into the anchorage or cable coverings.

(Continued on page 542)

*By Rolla E. Pollard. Abstract of Research Paper 1604, National Bureau of Standards, September 1944.

SELECTION OF BAR STEEL USED AS-ROLLED OR DRAWN

By John H. Frye, Col.
Assistant Chief, Research and Materials Division
Research and Development Service
Office of Chief of Ordnance
Washington, D. C.

BAR STEELS not to be heat treated are normally limited to carbon steels such as the plain carbon grades ranging from S.A.E.1010 to approximately 1050, the bessemer and openhearth screw steels, and the carbon-manganese grades. Any of these steels are available in two forms or conditions, namely, hot rolled and cold finished.

Hot rolled bars may be ordered with a specified grain size, tensile properties, minimum soundness, uniformity of composition or other restrictive requirements intended to produce steel of adequate characteristics for a given purpose. This material may be specified annealed, stress relief annealed, machine cut, or machine straightened. Surface condition may be specified as-rolled or pickled. When pickled the scale is removed by acid solutions and usually, to prevent corrosion in transit, subsequent oiling or liming is also specified.

The properties and characteristics of hot rolled bars are generally well understood; furthermore the various handbooks of steel producers and technical reports cover the data thoroughly.

Hot rolled bars in these grades should be used when their physical properties are suitable, when surface appearance and extreme accuracy to size and section are unessential, and when limited machining is to be done upon them. If the nature of the part is such that a moderate amount of machine work must be done, such as a step-down shaft, it is normally economical to use hot rolled bars. However, in the manufacture of many small mechanical assemblies there is usually considerable machine work involved, and hot rolled bars are not particularly adaptable; their use in screw machines is not recommended. During the depression years attempts were made to reduce costs by using hot rolled instead of cold drawn bars for the production of screw machine parts. Special collets had to be obtained to prevent slippage because of variations in size and out-of-roundness. However, the fine scale, even from pickled bars, mixed with the cutting oil to form an excellent lapping compound, which worked havoc with the machine bearings and tools. Also, as illustrated in Table I on the next page, it is necessary to machine off about 12% of the weight to clean up a bar if it is to be machined from hot rolled steel. The amount of machine work involved in producing the finished part will often indicate the economic selection. Consideration must also be given to the difference between purchase price of bar steel and selling price of chips, and to freight, handling and inventory charges.

This is the second part of a lecture given in an educational course presented last winter by the New York Chapter ASM. It is not to be regarded as the official viewpoint of the Ordnance Dept., U. S. Army, but as representing Col. Frye's personal opinions. The first part discussed the selection of plate steel, and was printed last October.

Table I — Size and Eccentricity Tolerances for Some Representative Bar Sizes, With Allowances for Turning

Size of Round	Finish	Size Tolerance	Eccentricity	Allowance for Turning to Size	Amount of Metal in Chips
1 in.	Hot rolled	−0.009	0.013	1/32	12%
	Cold drawn	−0.002	0.001*	None	
	Ground and polished	−0.002	.....	None	
2 in.	Hot rolled	+1/64	0.023	1/8	12%
	Cold drawn	−0.003	0.0015*	None	
	Turned and ground	−0.002	0.001*	None	
3 in.	Hot rolled	+1/64	0.035	1/8	8%
	Cold drawn	−0.004	0.002*	None	
	Turned and ground	−0.003	0.0015*	None	
4 in.	Hot rolled	+1/32	0.046	1/4	12%
	Cold drawn	−0.004	0.002*	None	
	Turned and ground	−0.003	0.0015*	None	

*No commercial standard; figures are maximum that may be expected.

Manufacturing economics are often the deciding factors in the selection between hot rolled and cold finished bars. Cold finished bars cost considerably more, and this difference in cost must be compensated for by reduced fabricating costs or increased performance in use.

Cold Finished Bars

Cold finished steel bars are known for their smooth finish, close dimensional tolerances, and improved machinability. However, it has only been in the last few years that they have been widely used by designers as an engineering material.

"Cold Finished Bars" is a term used collectively to describe a group of products manufactured from hot rolled rounds, flats, hexagons, squares, or special shapes, by cold drawing, turning and polishing, turning and grinding, or cold drawing and grinding. The characteristics of the product of each method of manufacture may be briefly described.

Turned and Polished Bars are hot rolled bars turned in a special purpose lathe and polished by passing through hardened burnishing rolls. A bright mirror-like surface finish is produced, together with extreme accuracy to size and concentricity. Since the surface working by the burnishing rolls is quite superficial, the physical properties and machinability are essentially the same as the hot rolled bar from which it was produced. Likewise there will be little if any warpage or loss in straightness when turned and polished bars are slotted or otherwise eccentrically machined. The burnishing rolls do create compressive stresses in the extreme outer fibers, thus materially increasing the endurance limit in bending, if the highest stressed portions retain the mill finish. This is in addition to advantages resulting from the improved surface.

Turned and Ground Bars are similar to turned and polished, except that instead of burnishing the bars are passed through a centerless grinder one or more times. The size accuracy is slightly closer than turned and polished bars, and the surface has a more satiny finish. Tensile properties and machinability are not changed from those of the hot rolled material.

Cold Drawn and Ground Bars are drawn through a die and finished by one or more passes through a centerless grinder. This product is sometimes known as jeweler's rod, needle bar, piston rod, and perhaps other terms descriptive of important uses. There is a marked increase in physical properties, in addition to the straightness, finish, and accuracy to size and concentricity. Unless strain annealed after cold drawing and prior to grinding, eccentric machine work will cause the bar to warp considerably. Since bars smaller than 1⅛-in. round are seldom turned and polished, or turned and ground, this material (cold drawn and ground) is ordinarily used in the smaller sizes for similar applications.

Turned and ground, turned and polished, and cold drawn and ground bars are normally used for shafting purposes, or in places where their appearance, straightness, concentricity, or accuracy to size will be of importance. Size of shafting required is usually dependent upon the bending stresses involved. Since stiffness against bending is entirely a matter of cross-sectional area, with chemistry or strength of the steel an irrelevant factor, it usually follows that the size required to withstand the bending stresses is more than adequate for strength purposes. Consequently a low carbon steel such as S.A.E. 1020 is normally suitable for shafting. When physical properties become a requirement, cold finished bars of higher carbon steels can be supplied.

Cold Drawn Bars (shipped without subsequent grinding) are produced by cold drawing scale-free hot rolled bars through a hardened die whose inside diameter is smaller than the diameter of the bar. The high combined compressive and tensile stresses acting on the bar cold work the metal uniformly and produce

(a) A smooth, bright bar relatively free from surface defects,

(b) Accuracy to size and concentricity,

(c) Increased machinability, and

(d) Increased tensile, yield, fatigue and hardness values.

The size accuracy, concentricity, and surface quality of cold drawn bars may make it possible to use the bar size and finish for such portions of the parts whose diameter coincides with that of the bar, thus saving machining time and waste of metal.

Cold drawn bars are best known for their machinability — so much so, in fact, that some of their other characteristics have been obscured. They machine more freely than the hot rolled bar from which they were produced, because of the changes in physical characteristics resulting from cold working. Increased hardness is usually given credit for this improvement, but personal observation has led me to believe that the ratio of yield to tensile strengths is also a factor of importance. If you consider that the machining of steel involves breaking a small part — the chip — from the original piece by shearing, it follows that to shear steel it is necessary to exceed *both* the yield and ultimate strength. The yield, being lesser, is exceeded first, and when this happens the metal around the area of the tool tip begins to flow. In a steel with a low yield value the volume of metal that will flow is large and the deformed volume builds up ahead of the tool and at the tool tip. This results in increased heat generation, higher power consumption, slower machining speeds, roughened or torn finish, and greater tool wear. On the other hand cold drawn steels, with the yield and tensile strengths brought closer together, exhibit "tool build up" to a much less degree. This improvement in machinability is not confined to the free cutting steels, but to all cold drawn carbon and alloy steels of low and medium carbon content.

Table II — Comparative Physical Properties of Hot Rolled (HR) and Cold Drawn (CD) Steel Bars

S.A.E. Steel	Condition	Yield Strength	Tensile Strength	Elongation	Reduction of Area	Brinell Hardness
1112	HR	40,000	67,000	27	47	140
	CD	73,900	87,000	17.5	48	179
X-1314	HR	....	....	..	..	...
	CD	68,000	80,000	19	51	163
X-1315	HR	45,000	71,000	28	52	135
	CD	70,000	82,000	18.5	50	167
X-1335	HR	56,000	90,000	22	40	179
	CD	89,200	105,000	16	35	217
X-1340	HR	60,000	92,000	20	35	185
	CD	95,200	112,000	14	30	223
1010	HR	29,000	51,000	38	70	101
	CD	55,000	67,000	25	57	137
1020	HR	45,000	67,000	32	65	137
	CD	63,700	75,000	20	52	156
1025	HR	41,000	70,000	31	58	130
	CD	68,000	80,000	18.5	50	163
1035	HR	55,000	88,000	30	56	179
	CD	78,200	92,000	17	45	187
1045	HR	60,000	99,000	24	47	200
	CD	86,700	102,000	15	35	207

Effect of Cold Drawing on Tensile Properties

As a result of the simultaneous compression and elongation which occur in the drawing operation, the physical properties are affected tremendously. Depending on the steel, its original condition, and amount of cold reduction, there may be an increase of 50% to 150% in yield strength, and 15% to 60% in tensile strength. The endurance limit is increased at least in the same proportion as the tensile strength. Hardness, of course, is also increased proportionately, while there is a corresponding decrease in elongation and reduction of area. The extent of these changes may be regulated by the amount of reduction in cold drawing. Table II (from S. L. Hoyt's "Metals and Alloys Data Book") and Fig. 1 to 3 indicate the average improvement in physicals and the mechanism of obtaining them.

Hot rolled physical properties quoted in Table II are those obtained as-rolled and reported as "average". Individual test values may vary widely and the figures quoted here should not be used as acceptance or rejection limits.

The cold drawn (CD) properties are likewise average and variable. Although it is not stated by the source, it is assumed that a nominal draft of $\frac{1}{16}$ in. was used on a bar about 1 in. diameter. These properties can be adjusted over a wide range by draft regulation and strain annealing. It must be remembered that the physical properties of cold drawn steels are dependent upon the chemistry, percentage of draft used, and upon the physical condition of the hot bar. The latter includes the as-rolled grain size, eccentricity, actual size, and finishing temperature on the hot mill. Hot bars for cold drawing purposes are given special attention and treatment, and these variables are restricted as closely as possible. However, since the cold drawing mill frequently has limited control over hot rolled bars, it is necessary to expect some variations from lot to lot in the end results.

Normalizing or annealing the hot bars prior to drawing produces greater uniformity. A more uniform product can be obtained by strain annealing after drawing. These operations increase the cost considerably.

Some steels are more sensitive to cold work

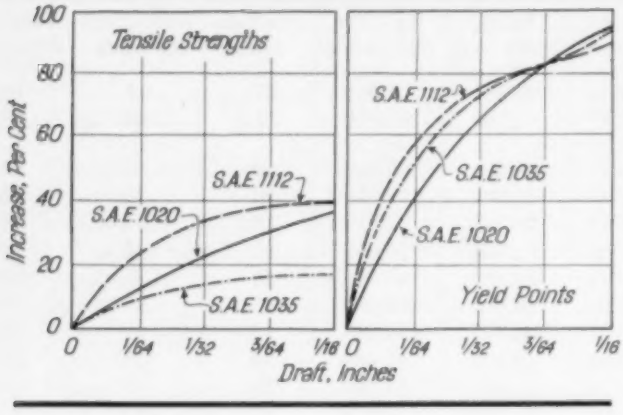


Fig. 1 — Characteristic Response of Three Grades of Bar Steel to Cold Work, Shown by Increased Tensile and Yield Strengths After Drawing ¾-In. Bars. (J. E. Beck, "Wire Magazine," January 1937)

than others. Figure 1 illustrates the characteristic sensitivity of three grades, S.A.E. 1020, 1035 and 1112. This must be considered by the mill when laying out drafting practices. Also, it is especially important that the consumer consider this when specifying cold drawn bars to minimum physical properties.

Use of Fractional Draft

It has been common practice in most cold finishing mills to use a fractional draft, such as $\frac{1}{16}$ in. reduction, for a wide range of bar sizes. This has the effect of applying varying percentage reductions as the original bar size varies; and Fig. 2 illustrates the variations in physical properties, size to size of finished bar, which may be expected by this practice.

This is also shown in Fig. 3. Test values for the latter were secured by cutting 30-ft. bars of $1\frac{3}{16}$ and $1\frac{9}{16}$-in. rounds of S.A.E. 1112 into short lengths and cold drawing the pieces with various drafts. The physical properties, plotted against percentage of cold reduction, are typical of the reactions to increasing cold work. Note the tapering off in hardness values as compared to the much more rapidly increasing tensile and yield strengths. It is also evident that the yield increases at a greater rate than the tensile strength and, when severely cold worked, the yield closely approaches the tensile value. More important, this chart shows that in the same grade, but irrespective of bar size, the physical properties obtained by cold drawing are dependent upon the *percentage* of cold reduction. For instance, a $\frac{1}{16}$-in. draft on the $1\frac{3}{16}$-in. hot bar is a reduction of 16%, whereas the 16% reduction on the $1\frac{9}{16}$-in. bar would require a ⅛-in. draft. This difference between a $\frac{1}{16}$-in. draft on the $1\frac{3}{16}$ and the $1\frac{9}{16}$-in. bar not only produces a great difference in mechanical properties, but also in the relative machinability. All who have worked with this material have noticed the difference in the machinability of small and large sizes of "cold drawn" bars of the same chemistry.

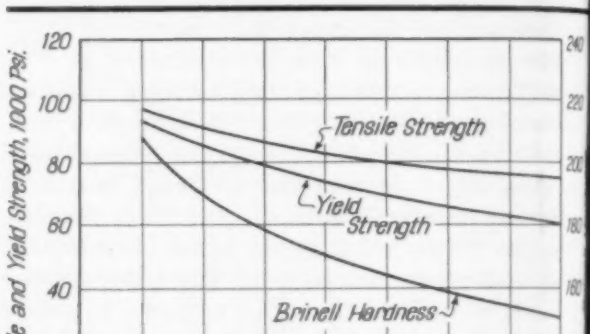


Fig. 2 — Effect of $\frac{1}{16}$-In. (Constant) Draft on Bars of Various Original Sizes of S.A.E. X-1314 Steel

Table III — Tests Showing Penetration of Cold Working

S.A.E. Steel	Diameter of Round	Draft	Diameter of Test Piece	Yield Strength	Tensile Strength
1112	¾ in.	1/16 in.	0.744	87,300	93,500
			0.685 *(a)*	87,100	93,600
			0.502 *(a)*	87,400	96,000
X-1335	$1\frac{1}{16}$	⅛ in.	0.505 *(e)*	105,300	111,000
			0.505 *(c)*	103,300	111,000
			0.505 *(c)*	102,300	111,300
			0.505 *(c)*	105,000	113,300
X-1020	2½	None	0.505 *(e)*	41,670	70,000
			0.505 *(c)*	35,000	66,700
		1/16 in.	0.505 *(e)*	65,000	75,000
			0.505 *(c)*	62,500	72,000

(a) Cold drawn bar turned to this diameter.
(c) Standard test bar machined from center.
(e) Standard test bar machined from edge.

In years past there existed an opinion that cold drawing produces a skin or case hardness, and if this case was machined off the benefits of cold drawing were lost. Actually, the cold working penetrates through the entire cross-sectional area

Table IV — Properties of Heat Treated Versus Cold Drawn Bars

S.A.E. Steel and Treatment	Yield Strength	Tensile Strength	Elongation in 2 In.	Reduction of Area	Brinell Hardness
1045, quenched in oil, tempered at 600°	95,000	140,000	15.0	41.0	278
1045, quenched in water, tempered at 900°	98,000	132,000	16.0	48.0	262
X-1335, cold drawn, 1/16-in. draft	95,000	115,000	14.5	40.0	235
X-1340, quenched, tempered at 900°	112,500	150,000	17.0	47.0	287
1080, quenched in oil, tempered at 900°	113,000	160,000	15.0	46.0	302
X-1340, cold drawn, 1/8-in. draft	112,000	121,000	13.5	40.0	241

Table III illustrates this fact. Data contained for the 2½-in. round for standard test bars cut near the edge *(e)* and near the center *(c)*, respectively, show that the hardness and tensile properties after 1/16-in. draft will actually be more uniform throughout than in the original hot rolled bar. Strain, like water, has the tendency to flow to the lowest level.

Some engineers believe that cold drawn bars lack "ductility". If we remain conventional and measure ductility by elongation and reduction of area, it is then fair to compare these properties of heat treated and cold drawn steel of the same yield value. Table IV compares the physical values of quenched and drawn 1045 and X-1340 with the same steels cold drawn to identical yield strengths. The differences in elongation and reduction of area are small but the differences in ultimate tensile strength (and particularly hardness) are considerable, and of special value to the machine shop.

Cold drawing mills are regularly supplying cold drawn bars, or drawn and strain annealed bars, to minimum physicals, often eliminating heat treatment of the machined parts, while maintaining a bright surface finish, accuracy and freedom from warpage. It is not suggested that the physical properties of all cold drawn steels can be identical with those obtained with heat treatment, but for many applications they are sufficient and desirable from an economic and fabricating viewpoint.

Aging Effects

In the past there has been some doubt concerning the stability of the physical properties obtained by cold drawing. From one point of view, it would seem likely that the internal stresses from cold working would tend to dissipate themselves over a period of time. This would certainly be in line with our experiences with coarse grained, skin pass, deep drawing sheets.

As a matter of fact, there *are* internal adjustments in the cold drawn bar which continue for many weeks, but the major changes in physical properties are completed within seven days after cold drawing.

To understand this reaction better from a practical viewpoint, tests were made by Columbia Steel & Shafting Co. (presented here through their courtesy). Several bars of one grade of steel, all from the same heat, were cold drawn, each with a different draft. Tensile tests from each bar were made as quickly as possible and at stated intervals from then on. In many cases, periodic tests were made for as long as two years after

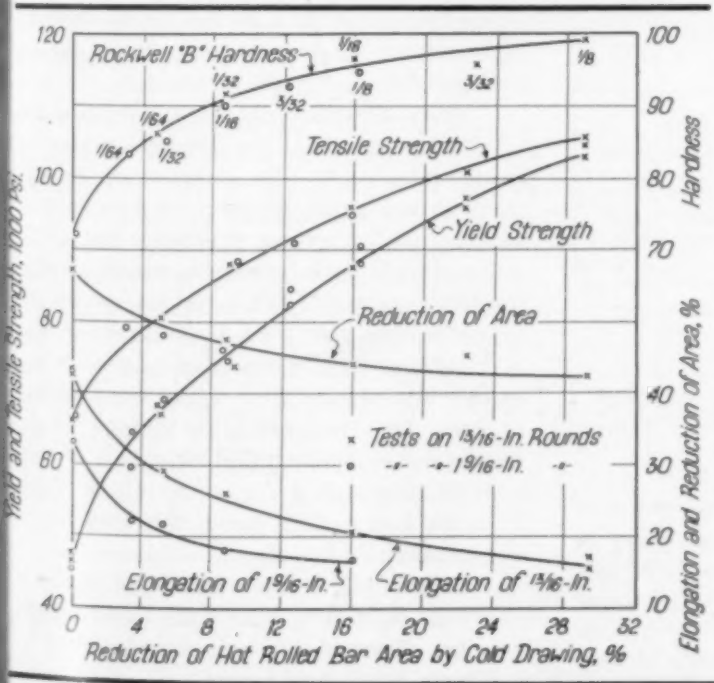


Fig. 3 — Effect of Various Drafts (Per Cent Reduction on Original Area) on Two Sizes of S.A.E. 1112 Steel. Note that figures for elongation require two curves; other properties depend on reduction rather than original size. (Courtesy Columbia Steel & Shafting Co.)

the cold drawing was completed.

The aging effect on bessemer screw steel $\frac{13}{16}$-in. round, drawn $\frac{1}{16}$ in. or 16% on area, is shown by Table V. Similar tests were made on this steel after drafts of $\frac{1}{64}$ in., $\frac{1}{32}$ in., $\frac{1}{16}$ in., $\frac{3}{32}$ in. and $\frac{1}{8}$ in., but lack of space prevents their record here. The trends are quite similar, and all the data are averaged and presented in graphical form in Fig. 4. It is interesting to note that the heavier drafts showed a lesser aging effect than the lighter drafts. Data for periods longer than 150 days are not available, except tests after aging for 18 months, and very little additional change had occurred in the time between 150 days and 18 months. Chemical analysis of this steel was 0.12% carbon, 0.85% manganese, 0.095% phosphorus, and 0.195% sulphur. It was coarse grained; the "inherent" grain size was 2 to 3; the grain size as-rolled was 4 to 5.

Table V — Effect of Aging on Cold Drawn S.A.E. 1112

$\frac{13}{16}$-in. round drawn $\frac{1}{16}$ in. on diameter, or 16% on area

Property	Tests on Hot Rolled Bar	Time of Test on Cold Drawn Bar			
		Immediate	2 Days	60 Days	150 Days
Yield strength *(a)*	45,540	83,960	83,500	....	86,900
	47,700	86,490	88,300	87,840	87,300
Tensile strength	67,630	88,800	90,600	95,500	95,800
	68,000	88,600	....	....	95,600
Elongation in 2 in.	42.5	14.0	19.5	20.5	22.0
	42.0	15.0	....	....	21.0
Reduction of area	57.7	26.9	42.4	43.9	44.2
	56.9	27.1	....	....	43.8

(a) Top value by divider method. Lower value by 0.2% set method.

A study of Tables V and VI, as well as Fig. 4, will show that the lower carbon 1112 shows more pronounced aging effects than the higher carbon 1135. The latter steel had the following composition: 0.40% carbon, 0.81% manganese, 0.015% phosphorus and 0.107% sulphur. Its "inherent" grain size was No. 4; as-rolled grain size was No. 6. Conditions of the two tests were quite similar. A week after cold drawing the changes in properties in bars drafted $\frac{1}{16}$ in. (as compared with the value for the bar soon after drawing) are as follows:

	S.A.E. 1112	S.A.E. 1135
Yield strength	+3.1%	+0.6%
Tensile strength	+3.2%	+0.5%
Elongation in 2 in.	+28%	+5.3%
Reduction of area	+52%	+7.8%

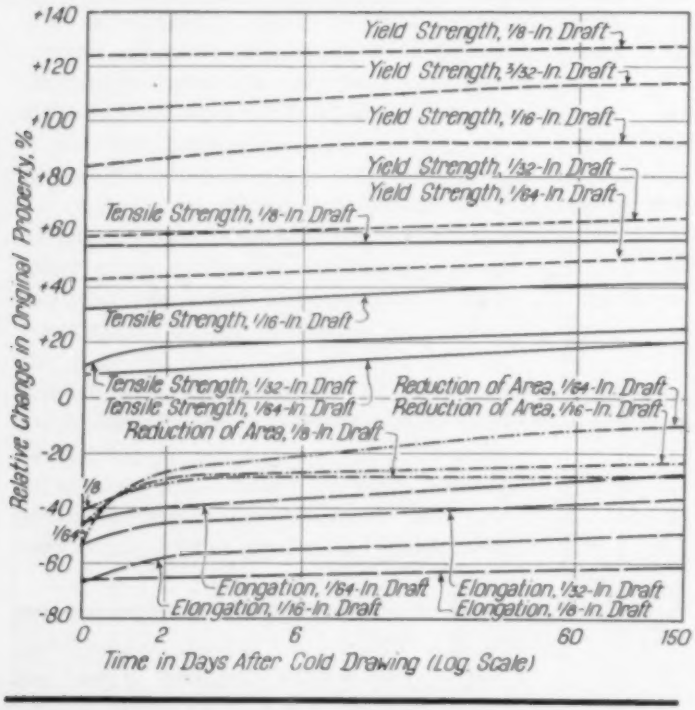


Fig. 4 — Effect of Age on the Tensile Properties of $\frac{13}{16}$-In. Bar of S.A.E. 1112, Cold Drawn Various Drafts ($\frac{1}{16}$-In. Draft Equals 16% on Area). Note that major changes occur in first week, and that bars after light drafts change more than those more heavily drawn

In addition, steels of similar composition will age to a varying degree; it is thought that deoxidation practice has much to do with this. As may be expected, strain annealing serves as a means for accelerated aging; after strain annealing there are no further changes in the properties.

From the data obtained it is possible to state: *(a)* That no prediction can be made relative to the amount of change through aging unless complete data on steel making and teeming practices are available, as well as information on the finishing temperature of hot rolling, eccentricity, and exact bar size. *(b)* A nominal increase in yield and tensile over that of the freshly drawn bar occurs after aging for a period of days. *(c)* An appreciable increase in the figures for elongation and reduction of area occurs after aging for a period of days. In some low carbon steels this increase is outstanding.

In general, it may be stated that for practical purposes, long-time aging effects can be eliminated from consideration in ordinary engineering uses.

Table VI — Effect of Aging on Cold Drawn S.A.E. 1135
$\frac{11}{16}$-in. round drawn various amounts

Property and Age	Hot Rolled Physicals	Reductions by Cold Drawing				
		$\frac{1}{16}$ In. or 5.9%	$\frac{1}{32}$ In. or 9.2%	$\frac{1}{16}$ In. or 16.5%	$\frac{3}{32}$ In. or 23.7%	$\frac{1}{8}$ In. or 30%
Yield strength	54,000					
6 hr.		70,200	82,460	91,800	99,200	103,700
2 days		69,240	81,200	91,600	100,500	102,300
7 days		67,040	84,400	92,320	103,000	104,020
Tensile strength	86,740					
6 hr.		90,340	94,200	101,500	109,250	111,000
2 days		90,600	93,830	101,600	108,000	113,300
7 days		89,600	94,900	102,000	110,300	114,700
Elongation in 2 in.	36.5					
6 hr.		28.0	25.0	19.0	16.0	14.0
2 days		28.0	25.5	19.0	16.0	15.0
7 days		31.0	23.5	20.0	17.5	16.5
Reduction of area	44.6					
6 hr.		43.8	35.5	35.7	36.3	34.9
2 days		43.6	39.9	37.5	35.5	35.8
7 days		45.1	40.1	38.5	37.4	35.1

Determination of Yield Strength

Increased yield strength has been one of the main sales points of cold drawn bars for constructional purposes. For many applications no further explanation of this term is necessary, but if cold drawn bars are always to be properly applied it is necessary to define yield strength. It has several "official" definitions in various much-used standards, such as the War Department's and the A.S.T.M.'s, but for our purposes it can best be explained by examining the stress-strain curve.

Hot rolled bars of low carbon steel act in an "elastic" manner — that is, the elongation is proportional to the tensile load — up to a certain point, whereupon a large elongation occurs with little or no increase in load. This increase is so sudden that the loading device ordinarily fails to keep pace, and the weighing beam on the testing machine drops, as though there were in fact a *decrease* in the load. This method of measuring "yield point" by "drop of beam" is the traditional way of testing the low carbon tonnage steels used in the as-rolled condition. The corresponding stress-strain curve is shown in Fig. 5, and the yield by drop of beam for X-1335 steel will be at about 60,000 psi.

Cold drawn steel, not stress relieved or annealed, has no marked "yield point" of this sort. In fact it is difficult to say, even, where the stress-strain curve departs from the straight portion and stress is no longer proportional to strain. The curve has a rounded or knee-type form, as shown in Fig. 5; consequently, there is no point at which increased deformation occurs without increased load, and as a result, no true "yield" point exists.

As a matter of convenience, the "yield stress" for material having this type of curve is determined by arbitrary methods such as the "agreed-upon extension under load" or "offset" methods. Either of these conventional methods permits a limited amount of permanent set — that is, the extensometer would not come back to

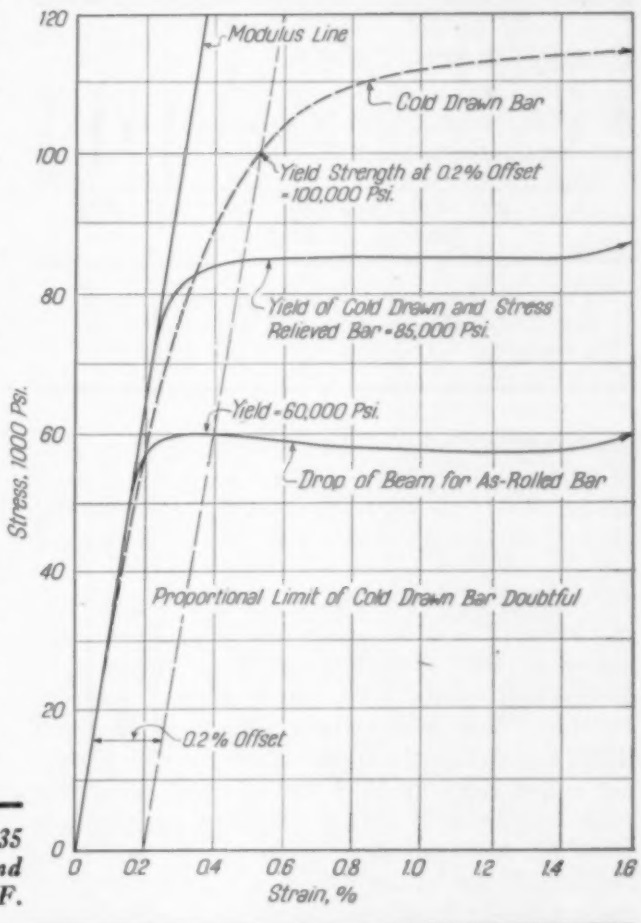


Fig. 5 — Stress-Strain Curves for S.A.E. X-1335 Steel, As-Rolled, Cold Drawn $\frac{1}{16}$-In. Draft, and Cold Drawn and Strain-Annealed at 1000° F.

zero elongation if the load were entirely released — before the yield value is determined. Figure 5, page 503, shows the method of determining graphically the yield value by 0.2% offset; a line is drawn parallel to the modulus line at a distance equal to 0.2% unit strain, and the yield is the point where it intersects the stress-strain curve.

Cold drawing will tremendously increase the yield strength, but the proportional limit will be reduced as indicated in the dotted curve of Fig. 5. Since the latter is the unit strength at which plastic deformation and a permanent set will occur, it follows that care must be exercised when dealing with "yield strength" for applications in which absolutely no plastic deformation is permitted. In such instances, the proportional limit of cold drawn bars can be tremendously increased by heating to an appropriate temperature below the critical.

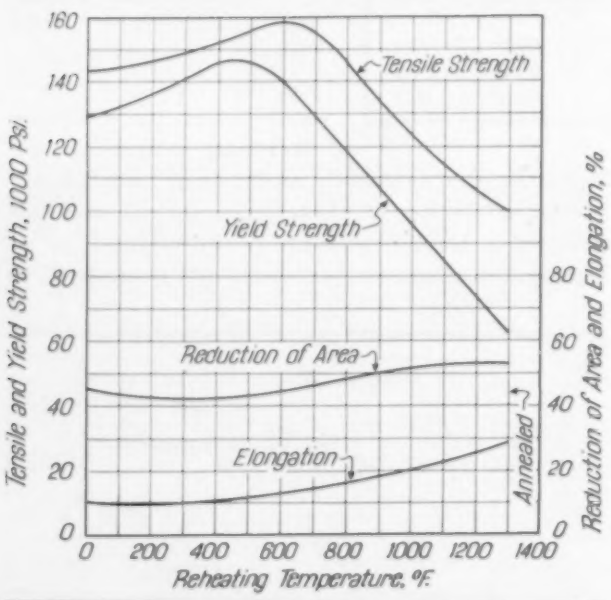


Fig. 6 — Average Effect of Strain Annealing Cold Drawn Bars at Various Temperatures. (Courtesy La Salle Steel Co.)

Curves in Fig. 5 show an enlarged section, at the knee, of a stress-strain curve made on cold drawn X-1335. Note the high yield strength, as determined by the 0.2% offset method, and the relatively low and indeterminate proportional limit, somewhat below the figure for the original hot rolled rod. Another stress-strain curve was made on the same steel after strain annealing at 1000° F. Note the definite yield point and, more important, the greatly increased proportional limit point of departure from the modulus line.

Strain Annealing

For many years it has been appreciated that cold worked steel will respond to temperatures below the critical. The degree of response depends upon the amount of cold work done, and the temperature to which it is heated. Up to approximately 700° F. the tensile and yield strengths and the hardness will increase, with negligible effect on elongation and reduction of area. Over this temperature, the effect is reversed. Advantage has been taken of this characteristic during recent years, and a product known as cold drawn, strain annealed bars has become an engineering material of considerable use.

The advantages of strain annealing are:

1. It straightens the knee in the stress-strain curve of cold drawn bars, thus increasing the proportional limit to essentially the yield stress.
2. It increases elongation, reduction of area, and impact strength without materially reducing the high yield obtained by cold drawing.
3. It prevents or reduces warpage when cold drawn bars are aged or are eccentrically machined.
4. Greater uniformity in physical properties can be obtained after strain annealing than in the untreated cold drawn bar.

By regulating the draft in cold drawing and the strain annealing temperature, a wide range of physical properties can be obtained. Reference to Fig. 6 shows the effects of strain annealing; the curves are representative in character but vary with the grade of steel and amount of cold reduction.

Cold Drawn Shapes

For the rapid duplication of parts having an odd shape, it is often advantageous to use cold drawn special sections, thus saving the slow, expensive machining from standard shapes. These useful shapes may be produced by cold drawing a special hot rolled shape, or from a standard shape by multiple cold drawing passes. Steels with a wide range of chemistries may be used, including free cutting, carbon, and alloy grades. Size accuracy of such drawn sections is generally comparable — at the least — with that obtained by ordinary machining operations. The usual bright, smooth, cold drawn finish and physical properties comparable with those of regular cold drawn sections are obtained. Such special cold drawn shapes are worthy of consideration when sufficient quantities are required to justify roll or die costs. It is then possible to reduce part costs 50% or more.

PREPARATION OF ULTRA-PURE CARTRIDGE BRASS

By J. L. Rodda
and Gerald Edmunds
Research Division
Technical Department
The New Jersey Zinc Co.
Palmerton, Pa.

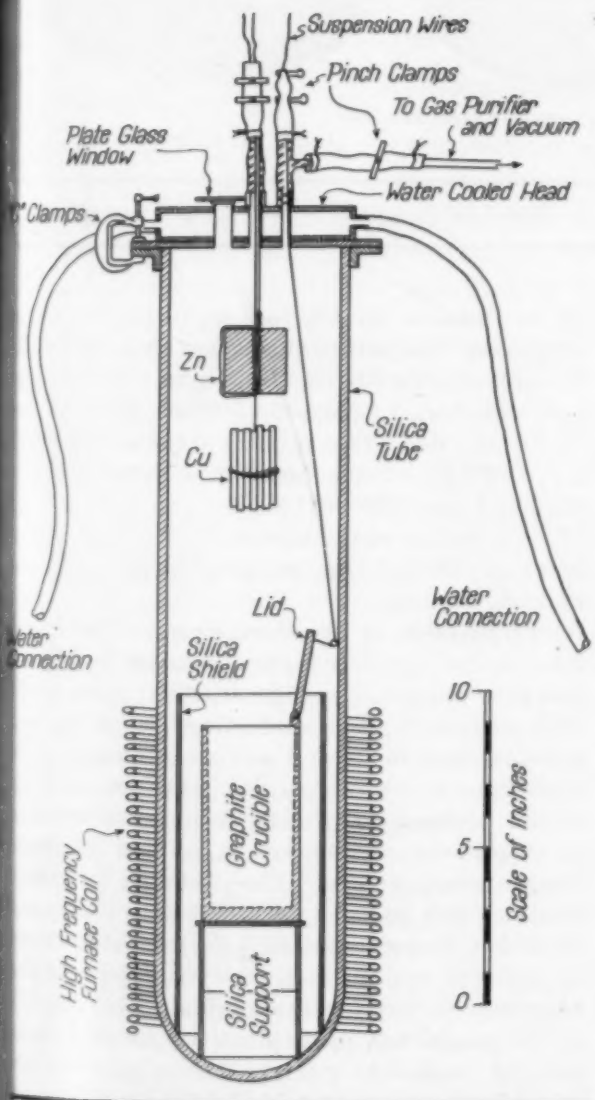


Fig. 1 — Apparatus for Melting Purified Copper and Zinc Into Ultra-Pure Cartridge Brass

IN ORDER TO DETERMINE the effect of impurities present in commercial cartridge brass upon its susceptibility to stress-corrosion, a comparison was desired between ultra-pure and ordinary brasses. This has been made possible by the production, in the laboratory, of a few pounds of cartridge brass from spectrographically pure zinc and copper of comparable purity under conditions which (it is believed) did not introduce any impurities, but may actually have accomplished some purification, particularly in regard to gas content and oxide films. This paper describes the preparation of the brass. While the method has been applied only to brass, with suitable modifications it may be applicable to other alloys, as well as to produce gas-free ingots of pure metals. Stress-corrosion cracking tests of the brass have already been reported to the joint A.S.T.M.-A.I.M.E. symposium on stress-corrosion cracking, Nov. 29, 1944. (As noted in *Metal Progress* for January 1945, page 78, it was found that the natural impurities in commercial brass have no appreciable effect on this phenomenon.)

Alloy Components — High purity copper was furnished by A. J. Phillips; it had a reported minimum purity of 99.999%. We alloyed it with selected lots of spectrographically pure zinc. The methods by which these two metals had been

Top, as removed from crucible. Bottom, as removed from crucible. Machined (weight 3.58 lb.).

Fig. 2 — Ultra-Pure Cartridge Brass Ingot Made in Graphite Crucible in Nitrogen Atmosphere

prepared have been described in *Transactions* of the American Institute of Mining & Metallurgical Engineers for 1941 and 1939, respectively.

The copper, in the form of ⅜-in. diameter cast rod, was sawed to 5-in. lengths, drilled through at one end to receive a wire for handling, and cleaned by successive immersion in concentrated HNO_3, 1:1 HCl, water, alcohol, and ether. Copper wire for suspending the copper during these cleaning operations and while it was in the furnace prior to melting was rolled and drawn to 0.042 in. from the same high purity copper, and cleaned by the same procedures.

As described in the 1939 reference above, the zinc was melted in one of two chambers of a double pyrex vessel having a ¼-mm. capillary in the connection between the chambers. Dry hydrogen was passed through the empty chamber and capillary, thence bubbled through the molten zinc. When the hydrogen pressure was reduced, the dross-free zinc flowed slowly through the capillary to the other chamber. The capillary drew the zinc from a point about ½ in. from the bottom of the charging chamber, whence it flowed into the bottom of the other chamber. The zinc was then solidified from the bottom upwards and the pyrex cracked away.

Zinc ingots produced in this manner were surface machined all over with an Armide tool to 1¾ in. diameter by 1½ to 2 in. in length, and a small axial hole drilled through with a steel drill. No contamination from this source is believed to have occurred. Analyses of turnings from the ingots indicated a lead content of between 0.00009 and 0.00037%, and a cadmium content between 0.0000034 and 0.0000047%.

All metal was handled with clean paper toweling. Rolled zinc was used in gripping the metal in the lathe.

Preparation of the Pure Brass — The essentials of the apparatus are indicated by Fig. 1. The view shows a graphite crucible; some melts were made with (non-conducting) dense alumina crucibles, and in these a section of cleaned mild steel pipe surrounded the crucible; in such runs a pressure of at least 50 mm. of nitrogen or argon was maintained to prevent excessive volatilization of iron. The Acheson graphite crucibles and lid were purified before use by the method for spectrographic electrodes described by Standen and Kovach in *Proceedings* of the American Society for Testing Materials for 1935.

Nitrogen was purified of oxygen and moisture by successive passage through alkaline pyrogallol solution, calcium chloride, and anhydrous granular magnesium perchlorate. Preliminary outgassing of the apparatus was done before the charge was suspended inside the tube.

The sequence of operations during alloying was as follows:

With the apparatus charged as shown in Fig. , the system was evacuated to a pressure of about 1 mm. of mercury or less. The crucible was heated to about 1350° C. (2450° F.), as indicated by an optical pyrometer sighted through the plate glass window, to outgas the system, particularly the graphite. Purified nitrogen was then let into the apparatus to slightly above atmospheric pressure. By loosening the proper pinch-cock, the copper and its pure copper binding wire were lowered into the crucible.

Fig. 3 — Top and Bottom of Ultra-Pure Cartridge Brass Ingot Produced in Alumina Crucible in Argon Atmosphere

At this time the whole system was again evacuated, the copper melted, and nitrogen led in as before. The zinc was then lowered into the crucible and the crucible lid was closed. After a few minutes for alloying, the silica tube and its contents were lowered slowly through the induction coil and the furnace current gradually reduced, thus allowing the ingot to solidify from the bottom upwards.

The entire operation, exclusive of final cooling, required about 8 hr.

In the most successful runs metal losses were below 2%. Photographs of ingots as removed from the crucibles, and after the surface had been removed are shown in Fig. 2. Analyses from tops and bottoms of the ingots were not significantly different. Spectrographic analyses showed no contamination other than a slight increase of iron in one ingot. There was some indication that sodium may have been picked up in the alloying process, but owing to the uncertainty of sodium analyses and the ubiquitous nature of this element, this is uncertain; if present, it was probably in non-metallic form. Some decrease in magnesium content was indicated for some of the alloys.

Some ingots were also made in alumina crucibles with both nitrogen and argon atmospheres. Analysis of the argon showed it to be free of oxygen and, therefore, it was passed through the drying train but not the pyrogallol. An ingot produced in an alumina crucible in argon atmosphere is shown in Fig. 3. When the surface of this ingot was machined off there was no porosity evident; it therefore existed only on the surface. It was probable that argon had been trapped between the melt and crucible. The surface of the cavities was bright.

Discussion — It is believed that these are the purest cartridge brasses ever produced. The ingredients were the purest obtainable, the analyses indicate no metallic contamination, and the procedure was such that gaseous impurities, if present, should have been reduced or eliminated.

Element	Maximum
Iron	0.0002%
Antimony	0.0001
Lead	0.0003
Cadmium	0.000002
Tin	0.0001
Nickel	0.0001
Bismuth	0.00001
Silver	0.00003
Arsenic	0.0002
Chromium	0.00005
Silicon	0.00001
Tellurium	0.0002
Selenium	0.0001
Sulphur	0.0001
Sodium	Possibly some
Calcium	Possible trace

The probable impurity maxima, in % by weight are given above. These figures are based upon the available analyses of the copper and zinc, and the absence of indications of contamination (except for a little iron in one ingot) by the spectrochemical comparisons of the product with the starting materials.

BITS AND PIECES

Quenching Oils

IF "PETROLEUMENSIS" may dare to make himself heard in "Metallurgicus's Own Department", he would like to comment upon views expressed in the December issue on the subject of "Quenching Oils". There is, in fact, little exception which can be taken to these views since the facts of the case are not at hand and will not be until, in the words of METALLURGICUS, "the fundamental principles of quenching have been explored".

We do question, however, the implications of his remarks and the philosophy upon which they are apparently based.

Remembering that the proverbial chain is no stronger than its weakest link, we find it somewhat inconsistent for a metallurgist "to provide the best possible quenching facilities", as suggested, and then toss in a 10¢ per gal. oil. While we share the universal respect for economy, we do not synonymize it with initial cost. Such factors as doubled or tripled useful life of a quenching oil, and the use of a medium the composition of which has been selected from a knowledge of the needs of the particular job to be done, can very easily whittle down the real margin in price as well as remove the psychological sting of the "never-ending price per gallon for the oil consumed" (quoting from December).

The coach of the successful football team does not try to plug up that hole in the line by looking around for the best material in the country for the other ten positions. Likewise, the wise operator regards the quenching medium as an essential, integral factor of the operation and selects, as nearly as possible, a material which is tailored for the job.

Admittedly, all of the answers to quenching problems are not available. But they are still being actively tackled, and from the results obtained there is plenty to justify the use of oils *which are designed to quench*, even if they do cost more than a dime a gallon.

And so we want to differ with "Metallurgicus" on only one, but a very significant point: In line with best judicial practice, let's not assume guilt before it is established, and instead of using any "100 at 100" oil until the need for something better is established, let's consider the merits of a product on the basis of its performance.

PETROLEUMENSIS

Lead Foil as Base for Next to Last Step in Metallographic Polishing

LEAD FOIL has been used by several departments in the Watertown Arsenal Laboratory for about three years as an aid in the intermediate stages of the preparation of metallographic specimens. The technique has been found to be a rapid, convenient means of preparing extremely flat metallographic surfaces with minimum distortion of structure, complete retention of inclusions and excellent preservation of edges.

The process has been used principally as an intermediate step between 000 metallographic paper and the final polishing operation, serving the same purpose as an abrasive-impregnated lead lap. However, there are serious difficulties in polishing with the latter, using the methods suggested by Kurt Amberg in *Metal Progress* for February 1940. Best results are obtained only on a freshly machined surface, since one which has been used a few times produces scratches of uneven depth, exceedingly difficult to remove. Thus the rotating lead lap gives variable results and involves frequent resurfacing.

The lead foil process, in use at Watertown, eliminates these difficulties, giving consistently good results with a minimum of effort. The technique can be acquired in a relatively short time, and the operation then takes only about a minute for specimens up to ½ in. square mounted in bakelite. Starting with a ground surface, it usually requires 10 to 15 min. to produce a true metallographic polish.

The polishing procedure is as follows:

A 5-in. square of annealed lead foil about 0.002 in. thick is rinsed under running water and placed on a plate of thick glass and stroked with the fingers until flat. A small quantity of alumina suspension is placed on the lead and spread over the foil with a light rubbing action, and the surface is ready for use. The specimen is polished with short straight strokes (1 to 2 in.) or with a circular motion, preferably the former. Pressures which gave best results were found to range from about 1 to 4 psi., as determined by dressing a specimen on one pan of a dispensing balance.

Several conditions must be controlled to obtain consistently good results:

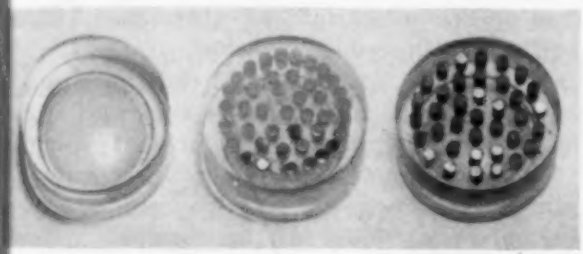
1. The abrasive suspension must not have too broad a distribution *(Continued on page 625)*

BITS AND PIECES

Mounts for Fine Wire and Thin Sheet

JUDGING from numerous recent items in "Bits & Pieces", metallographers are having much needless trouble in mounting small specimens of wire or thin sheet.

For mounting wires where the cross-sections are to be examined, use the steps shown in the figure. The first step is simply to mold a blank of the desired height. (I use lucite or transoptic mounting powder.) This then is drilled with a number of holes equal to the number of cross-sections to be examined. (A machinist's set of numbered drills will give all sizes necessary; it is best to drill the holes very slightly larger than the wire.) The wires are then cut and either



ground off or filed flat and placed in their respective holes. Cut the wire a little shorter than the depth of the hole; do not bottom it but let it protrude slightly. The partially prepared mount is then placed in the mounting press and re-processed the same as making a new mount from powder. No additional powder is necessary. The engraving shows, at the left, the molded blank; in the center is the drilled blank with some of the wires in position; at the right is the re-processed and finished mount.

If longitudinal and transverse sections of the same wires are to be mounted together, the longitudinal sections can be placed in the mount when originally made, leaving room at one side or end for the transverse sections, which are placed in drilled holes and the mount re-processed.

In mounting the edges of thin sheets, a similar method is used, wherein slots are cut into the blank slightly wider than the thickness of the specimen. The specimens are pressed into these slots and the mount re-processed. Several thicknesses of saws ranging from the very thin jeweler's saw to the quite thick power saw blade can be obtained for this purpose.

Where extremely thin or fragile sheet specimens are to be mounted, they may be clamped in a vise between thin sheets of lucite or plexiglass and wrapped with a rubber band. This pack is then placed in the mold the same as a larger specimen requiring no special technique, powder added and processed.

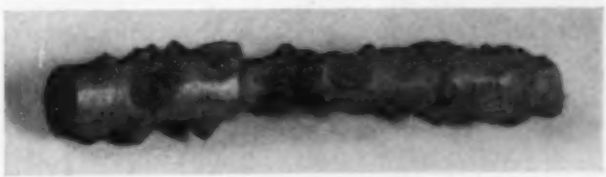
Make any required markings for identification on a small piece of paper. When filling the mold with powder, withhold a small portion to cover this piece of paper, position it by a small wire, carefully add the remaining powder and process as usual.

Incidentally, in case you run out of mounting powder, old mounts no longer needed can be crushed and re-used. (C. G. ZUR HORST, Metallurgist, Gulf Research & Development Co.)

Why Did It Sprout?

THE ACCOMPANYING PHOTOGRAPH does not represent a log of wood with lichens or corals attached, but an aluminum alloy test bar which may be something of a metallurgical curiosity. At one time we thought we knew the cause, but now we are not so sure. Maybe some other ASMembers have seen aluminum castings that erupt in a similar way during heat treatment in a bath of molten nitrate and have found a satisfactory explanation and cure. While our rejects from this cause are not high, they do appear spasmodically in a disturbing way.

Obviously there must be some very active material either on or just beneath the surface of



the castings. Microscopic examination showed that the aluminum matrix had been attacked. The suggestion that the trouble is due to particles of trapped foundry flux is not valid, for no flux is used in our foundry. Blaming the nitrate heat treating bath is not valid, for when castings sprout, they will also sprout when heat treated in an atmosphere furnace.

X-ray diffraction patterns of particles of

metal broken from the excrescences showed lines of a complex compound not identifiable in published diffraction data. These particles contained a notable amount of water soluble chloride, identified as common salt. It is possible that this is residual from a degasifier or flux which might have been used by the makers of our foundry ingot (which is secondary metal) but the ingot makers disclaim responsibility. (JOHN B. ZAPPONE, Chief Chemist, Robertshaw Thermostat Co.)

Brazing Keys Into Shafting

OUR PREVIOUS METHOD of permanently fastening keys into keyways had proven unsatisfactory from both a quality and a cost standpoint. The shaft is 1-in. cold drawn 1045 steel and the key is ¼ in. square by 1½ in. long. A 0.005-in. shim of brazing alloy (1175° F. melting point) was fitted into the keyway and the key pressed in over it. The parts were of course washed.

The first method of heating for brazing was by induction. It took only 4 to 5 sec. but several difficulties appeared. The inductor block available did not allow us to press the key during brazing, and we were skeptical of the uniformity of results we might get in production. More important, enough heat was generated in the shaft by the current available to us to soften the shaft and lower its strength. (This could probably be overcome by a short timed quench after brazing.)

We thereupon turned to resistance heating, using a 75-kva. pedestal spot welding machine equipped with an interrupter timer. Electrodes were made of copper and were about 2 in. square, the bottom electrode being grooved to accommodate the round shaft and the top being flat for the key. About 12 sec. time and 24 interruptions of current were necessary to braze the key into the shaft. Inasmuch as the heated area in the shaft was confined very closely to the key, the cold mass of the shaft cooled the heated area fast enough after brazing so the strength was not appreciably impaired. It was found necessary to braze while the flux was still wet; apparently after the flux dried enough resistance was created to prevent the current passage, and consequently the shaft failed to heat. (T. L. BURKLAND, John Deere Harvester Works)

Identification of Nickel Alloys by Spot Tests

THE FOLLOWING PROCEDURES will distinguish among monel, "S" monel, "K" monel, nickel, "D" nickel, 30% copper-nickel, nickel silver, inconel, chromium-iron and chromium-nickel stainless steels, Ni-resist, ordinary steel, and cast iron. Before testing, the material should be cleaned with emery cloth or a file to remove dirt, grease, corrosion products, paint or any metallic coating such as galvanizing.

Test With a Strong Horseshoe Magnet

I. If the material is strongly magnetic, it may be nickel, "D" nickel, ordinary steel, cast iron or chromium-iron stainless steel. Distinguish as in Procedure A, below.

II. If the material is slightly magnetic, it probably is ordinary monel or cold worked 18-8 stainless steel with or without molybdenum. (This magnetic test should be made preferably after cooling the metal with ice water or a freezing mixture, which will increase the magnetic strength and distinguish better between monel and nickel-copper alloys of lower nickel content, such as nickel silver.) Heat the specimen in hot water, preferably boiling, and retest with a magnet while hot. If the specimen has no magnetism when hot it is monel. Confirm, if doubtful, by Procedure B, below.

III. If the material is non-magetic, it may be copper-nickel, nickel silver, "K" monel, "S" monel, inconel, annealed or quenched chromium-nickel stainless steel with or without molybdenum, or Ni-resist. Confirm as in Procedure C, below.

Procedure A; for Strongly Magnetic Materials

Place a drop of concentrated nitric acid on a cleaned area.

(a) If the acid reacts slowly to a pale green color, the material is nickel or "D" nickel. To distinguish between nickel and "D" nickel: Add a drop of concentrated nitric acid and react, then add a drop of water and stir with a glass rod; finally add a little sodium bismuthate and stir. A purple color indicates "D" nickel; a brown color indicates nickel. *(Continued on page 627)*

MECHANICAL PROPERTIES AND WELDABILITY OF HIGH STRENGTH PLATE

By George F. Comstock
Metallurgist
Titanium Alloy Mfg. Co.
Niagara Falls, N. Y.

The investigation of high strength plate steel (small heats melted in laboratory equipment) reported in METAL PROGRESS *for last December has been extended to include commercial plates of similar analyses, made under the conditions of actual steel mill practice, in order to determine whether the preliminary conclusions would apply to tonnage production. The excellent properties and weldability of manganese-titanium steel is confirmed by these tests on commercial plates from several sources.*

ALL SAMPLES USED in this study with one exception were cut from ½-in. plates, made in the openhearth, and supposedly in as-rolled condition. Nine plates of Mn-Ti steel from three sources, one Mn-V plate, and three Mn-Ti-V steel plates from different mills are included. One of the latter (No. 13 of Table I) had relatively low manganese and high silicon; it was also exceptional in being an electric furnace steel and the plate was ⅞ in. thick.

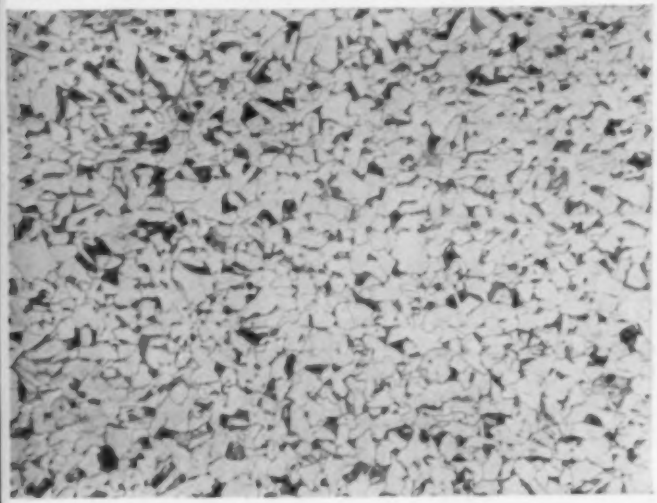
All test specimens were cut lengthwise in the direction of rolling, and in the specimens for notched bar impact tests the notches were all made parallel to the surface of the plate. The tests included tensile tests in three conditions of heat treatment, notched bar impact tests at three temperatures, work-brittleness tests to show

Table I — Chemical Analyses of Samples

No.	Type of Steel	Source	C	Mn	P*	S*	Si	Cu*	Ni*	Cr*	Mo*	V	Total Al	Total Ti
1	Mn-Ti	A	0.14	1.31	0.025	0.024	0.22	....	....	0.24	.....	.....	.....	0.033
2	Mn-Ti	A	0.14	1.27	0.024	0.030	0.22	....	....	0.04	.....	.....	0.015	0.032
3	Mn-Ti	A	0.14	1.17	0.028	0.030	0.22	....	....	0.03	.....	.....	.....	0.024
4	Low Mn-Ti	A	0.16	0.73	0.022	0.034	0.21	0.02	0.05	0.24	0.004	0.004	.....	0.057
5	Mn-Ti	B	0.17	1.34	0.031	0.028	0.32	0.13	0.12	0.07	0.020	0.003	.....	0.013
6	Mn-Ti	B	0.16	1.31	0.016	0.033	0.33	0.11	0.13	0.04	0.026	0.004	.....	0.015
7	High Mn-Ti	B	0.17	1.59	0.020	0.040	0.25	0.03	0.03	0.04	0.002	0.004	.....	0.041
8	Mn-Ti	B	0.13	1.26	0.013	0.029	0.25	0.05	0.10	0.02	0.004	0.004	.....	0.035
9	Mn-Ti	C	0.14	1.25	0.024	0.020	0.24	....	....	....	.....	.....	0.02	0.018
10	Mn-V-Ti	C	0.15	1.11	0.022	0.027	0.30	....	....	....	.....	0.04	.....	0.023
11	Mn-V-Ti	D	0.14	1.29	.....	.....	0.34	....	....	....	.....	0.02	0.02	0.015
12	Mn-V	E	0.15	1.13	0.013	0.023	0.25	0.24	0.18	0.10	0.03	0.087	.....	.....
13	Si-V-Ti	F	0.14	0.68	0.018	0.027	0.55	0.17	0.11	0.09	0.03	0.11	.....	0.046

*Steel mill analysis.

Fig. 1 — Steel No. 3, As-Rolled (0.14% C, 0.024% Ti)



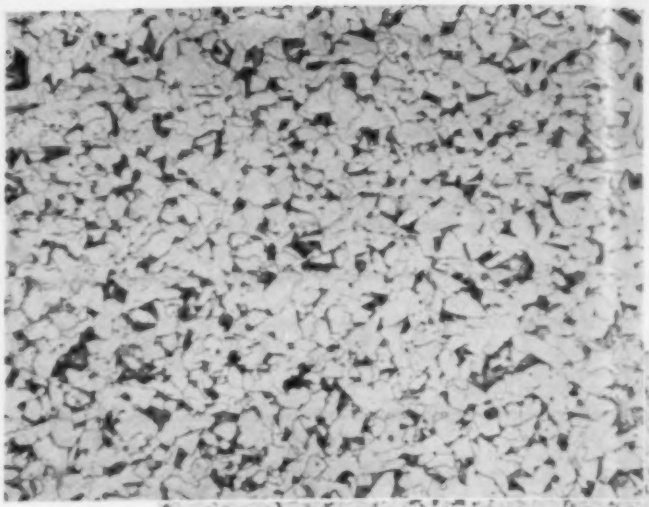


Fig. 2 and 3 — Steel No. 4, As-Rolle (Top) and Normalized. (0.16% C, 0.057% Ti

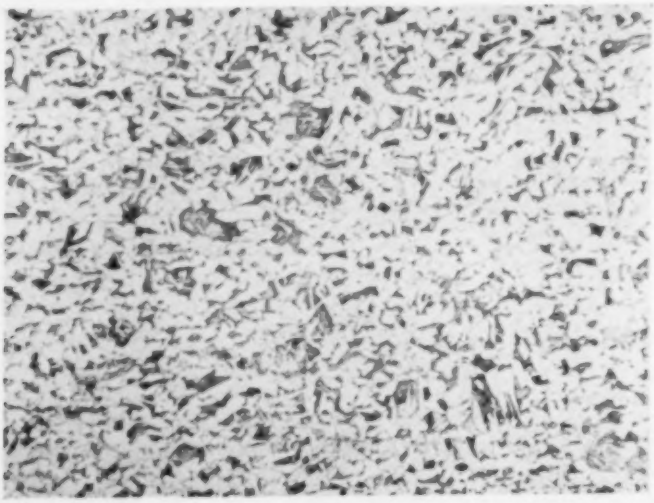


Fig. 4 (Above) — Steel No. 5 (0.17% C, 0.013% Ti)

Fig. 6 (Below) — Steel No. 11 (Mn-V)

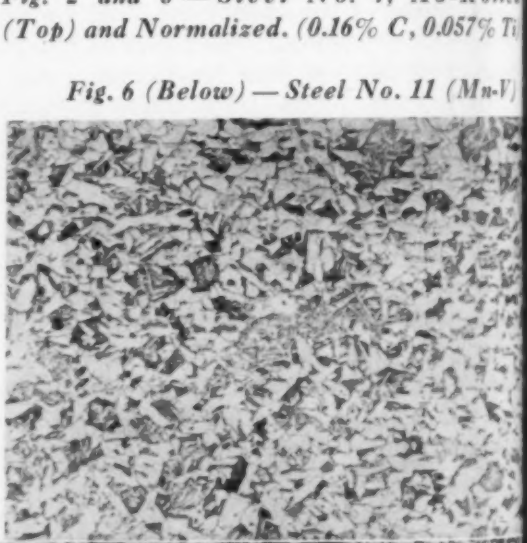
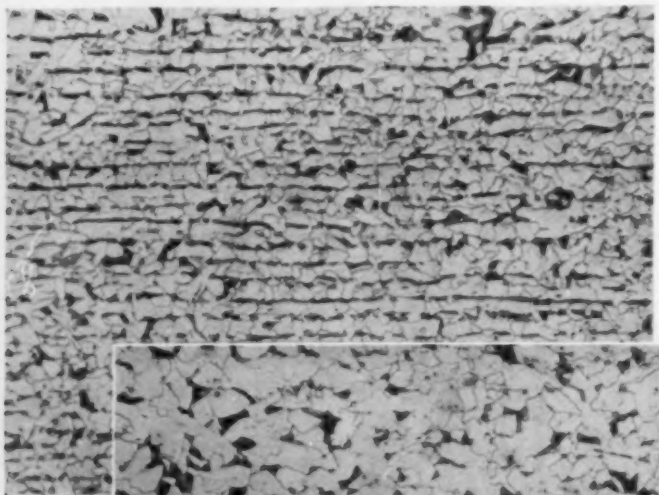
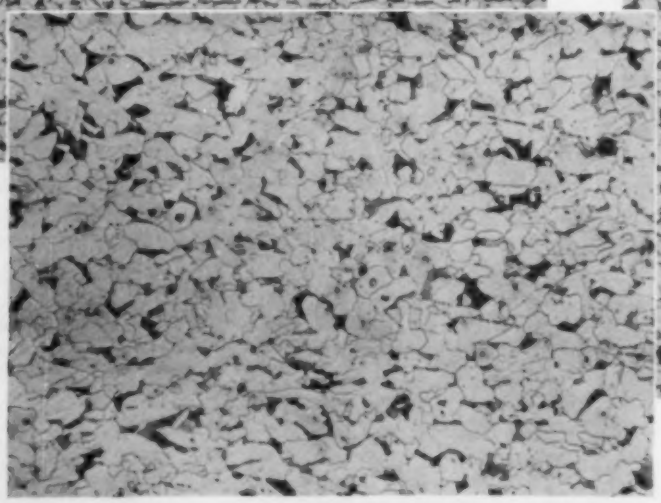


Fig. 5 (Below) — Steel No. 9 (Mn-Ti)





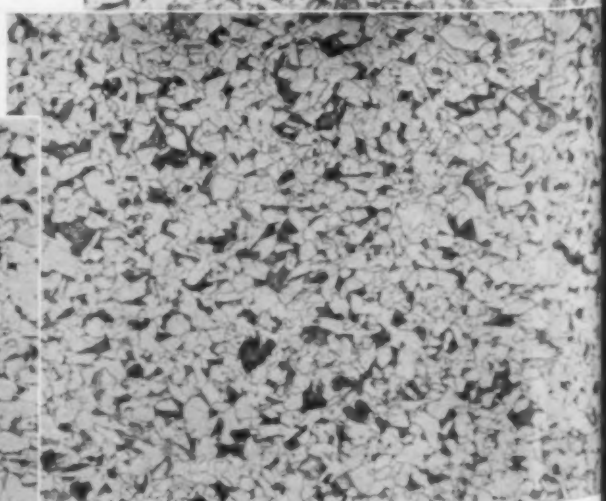


Fig. 7 (Above) — Steel No. 12 (Mn-V)

Fig. 8 — Steel No. 13 (Si-V-Ti); 7/8-In. Plate

No.	Type of Steel	As-Rolled Specimens					Stress-Relieved at 1100° F.					Normalized at 1600° F.				
		Yield Point	Tensile Strength	Yield Ratio	Elon. in 2 In.	Red. of Area	Yield Point	Tensile Strength	Yield Ratio	Elon. in 2 In.	Red. of Area	Yield Point	Tensile Strength	Yield Ratio	Elon. in 2 In.	Red. of Area
1	Mn-Ti	53,800	75,000	71.8	34.0	72.5	53,000	73,800	71.8	34.5	72.7	52,600	71,400	73.8	35.0	75.5
2	Mn-Ti	50,300	71,500	70.4	31.0	70.0	49,600	70,300	70.6	32.0	70.4	47,400	68,000	69.7	34.0	73.0
3	Mn-Ti	49,200	68,700	71.6	36.5	70.8	47,300	67,500	70.1	35.0	72.1	48,600	69,900	69.5	35.0	72.9
4	Low Mn-Ti	58,900	82,000	71.9	21.5	61.9	59,000	80,600	73.2	23.5	60.9	53,600	69,400	77.3	34.0	70.2
5	Mn-Ti	55,400	82,000	67.5	29.0	70.2	56,300	79,800	70.6	29.0	69.7	58,100	82,000	70.9	31.0	70.4
6	Mn-Ti	54,500	81,700	66.7	28.0	71.5	54,900	77,900	70.5	30.0	68.2	58,200	80,200	72.6	30.0	72.5
7	High Mn-Ti	54,900	79,900	68.7	28.5	60.0	55,000	78,300	70.3	29.5	58.5	55,100	71,400	77.3	32.5	64.0
8	Mn-Ti	51,200	74,200	69.0	30.0	73.2	52,200	70,000	74.6	32.0	70.4	51,600	69,600	74.1	33.5	73.8
9	Mn-Ti	51,200	72,100	71.0	33.5	69.3	50,300	70,000	72.0	35.5	69.3	54,500	71,400	76.4	37.5	73.0
10	Mn-V-Ti	53,100	74,900	71.0	34.0	67.6	53,300	76,000	70.2	34.5	66.3	54,900	72,600	75.6	37.5	71.0
11	Mn-V-Ti	52,500	78,500	66.9	30.5	66.8	56,600	77,000	73.5	31.0	67.6	54,800	79,600	68.8	32.5	70.4
12	Mn-V	59,000	85,600	68.9	24.0	68.4	69,100	86,600	79.8	25.5	67.7	61,500	78,000	78.9	32.5	71.5
13	Si-V-Ti	53,500	72,500	73.8	30.5	66.8	53,500	72,900	73.4	33.0	67.5	47,600	69,300	68.8	36.5	70.6

strain-aging embrittlement, end-quench hardenability tests using ½-in. diameter specimens, weld-hardening and notch-impact tests, and three varieties of notch-bend tests to show the ductility of the heat affected zone below a fusion weld.

Typical Microstructures, lengthwise, are shown in Fig. 1 to 8, at magnification of 100 diameters after etching with nital. Manganese-titanium plates No. 1, 2, 3, 6, and 8 were practically indistinguishable in structure; Fig. 1 can be considered typical of these five. Sample No. 4 was very slightly coarser (Fig. 2); when normalized, its structure became much finer (Fig. 3) and this was true also of the other steels. (The normalized pieces were small as compared with commercial plate sizes, and cooled rapidly in air.) Samples No. 5 (Fig. 4) and 7 showed more pearlite than the others, their carbon contents being a little higher; in No. 7 (not illustrated) the pearlite was coarser and more sorbitic on account of the high manganese.

Sample No. 9 (Fig. 5) had a very distinctly banded structure, and differed greatly from most of the others in this respect. Sample No. 10, from the same source, was less banded but more dirty, with prominent streaks of inclusions resembling alumina. Sample No. 11 shown in Fig. 6, from a different source, was not banded, but was distinguished by prominent colonies of rather coarse acicular pearlite, as though it had been rolled hotter than the others. Sample No. 12, the vanadium steel (Fig. 7), was not especially fine grained in respect to the pearlite, but showed scattered patches of very fine ferrite grains, more or less typical of vanadium steels. Sample No. 13, with low manganese and high silicon, showed less pearlite than the others, and the slightly coarser structure shown in Fig. 8 was due, possibly, to the fact that it was rolled to only ⅞-in. thickness.

Tensile Test Specimens were cut lengthwise about 6 in. long and ¾ in. wide, and turned to about 0.45 in. diameter with a gage length of 2 in. One specimen from each sample was tested in the as-rolled condition, one after stress-relieving for 3 hr. at 1100° F., and one after normalizing 1 hr. at 1600° F. Yield points were determined in most instances by drop of beam, but were also checked by noting with a strain gage the stress producing 0.5% elongation, which was relied on when the drop of the beam was not well marked. All the fractures were free from flaws, except for a few laminations in steel No. 10, where so many inclusions were present.

The results of the tensile tests are reported in Table II. They show that all these steels met the Navy specification for high strength plate of ½-in. thickness, namely, at least 48,000 psi. yield point, and not over 87,000 psi. tensile strength in the as-rolled condition. A few of them had lower yield points however after heat treatment. The vanadium steel No. 12

had specially high yield strength and yield ratio, but rather low elongation except when normalized. The low manganese, high titanium steel No. 4 also had rather high yield strength and low ductility except when normalized. The high manganese steel No. 7 had comparatively low reduction of area in all conditions — even when normalized.

Otherwise the tensile properties listed in Table II seem reasonably uniform and consistent — in fact less variable than might have been expected from the differences in microstructure. They are in generally good agreement with those reported in last December's article describing laboratory-melted steels of similar composition. It is interesting to note that while normalizing reduced the yield point of most of the higher-titanium steels (No. 1, 2, 3, 4, 7, and 13 — No. 8 being an exception) it raised the yield point of the lower titanium steels while generally reducing their tensile strengths. The reduction in yield point in the former was undoubtedly due to a change in the mode of occurrence of the titanium in the steel, while the increase in the latter was due merely to grain refinement.

Notched Bar Impact Tests — Charpy impact tests were made on lengthwise specimens of standard size, with a V-notch 0.079 in. deep parallel to the surface of the plate. Tests were made in duplicate at three different temperatures as noted in Table III. All specimens were of steel in the as-rolled condition.

Table III — Impact Tests of As-Rolled Bars At Different Temperatures

No.	Type of Steel	Ft-Lb. at 70° F.	Ft-Lb. at 32° F.	Ft-Lb. at −30° F.
1	Mn-Ti	199; 173	176; 175	6.0; 4.7
2	Mn-Ti	142; 123	154; 141	9.3; 6.4
3	Mn-Ti	173; 180	180; 169	6.8; 6.1
4	Low Mn-Ti	6; 6	3; 3	2.2; 2.3
5	Mn-Ti	154; 155	41; 124	7.8; 5.8
6	Mn-Ti	118; 128	31; 44	6.4; 5.1
7	High Mn-Ti	42; 44	10; 12	3.1; 2.9
8	Mn-Ti	146; 153	54; 20	3.1; 5.2
9	Mn-Ti	153; 136	123; 135	124.0; 151.0
10	Mn-V-Ti	146; 158	142; 31	4.0; 5.9
11	Mn-V-Ti	135; 108	24; 26	5.3; 4.5
12	Mn-V	71; 44	10; 13	2.8; 2.7
13	Si-V-Ti	32; 77	14; 8	2.6; 3.7

These reveal much greater differences between the samples than the tensile tests did. The low manganese, high titanium steel No. 4 (with 0.24% chromium) is evidently quite brittle or notch-sensitive. The high manganese steel No. 7, the vanadium steel No. 12, and the silicon steel No. 13 gave the next lowest values, both at room and lower temperatures. The next better in line, having moderately good quality in regard to notched impact resistance, are the manganese-titanium steels No. 6, 8, 11, 5 and 10, the latter two each having one very good value at 32° F. Steels No. 1, 2, and 3 were very good at 32° F., but poor, like most of the others, at −30° F.

Steel No. 9 however was outstandingly good even at −30° F. Since its microstructure was banded like the structure of the normalized sample of No. 4 (Fig. 3), a suspicion arose that this sample might have been normalized at the mill. Impact tests were therefore made on normalized specimens of a number of the other steels for comparison, with the following results:

	Tested at Room Temperature	Tested at −30° F.
Steel No. 1	—	206; 198
Steel No. 4	145; 137	135; 165
Steel No. 6	—	34; 105
Steel No. 7	65; 63	—
Steel No. 8	—	127; 149
Steel No. 10	—	156; 189
Steel No. 12	111; 116	72; 78
Steel No. 13	155; 131	—

Evidently normalizing gave much better impact values at low temperature, and it seems that steel No. 9 must have received some treatment prior to receipt, like normalizing, different from the other samples — perhaps accidentally during the rolling.

It is interesting to note the enormous difference in impact value brought about by normalizing steel No. 4. The acid-soluble titanium was determined chemically in this and some of the other samples, with the following results:

	Titanium	
Steel	Acid Soluble	Total
No. 1, as-rolled	0.011	0.033
No. 4, as-rolled	0.021	0.057
No. 4, normalized	0.007	0.057
No. 6, as-rolled	0.005	0.015
No. 8, as-rolled	0.012	0.035
No. 9, as-rolled	0.005	0.018

It appears therefore that the low impact resistance of sample No. 4, as-rolled, could be explained by the occurrence of too much of the 0.057 titanium it contained in solution in the ferrite, since with lower soluble titanium — both in this steel and in others — the impact values were much better. The chromium content of steel No. 4 may be also significant in this connection, however, although chromium occurred as well in the satisfactory steel No. 1. Larger amounts of both titanium and chromium carbides in solution in the as-rolled condition as compared with the normalized condition could account for the differences both in tensile ductility and in the

impact values. Vanadium carbide in steel No. 12 probably acted in the same way, as indicated by the impact results.

The microstructures are evidently of little value as an indication of notch toughness or brittleness in such steels where carbides in solid solution in the ferrite may promote notch sensitivity. In manganese-titanium steel without chromium, and with total titanium below 0.05% however, all available evidence indicates that no detrimental quantity of titanium will remain in solution in the ferrite in any steel produced under commercial soaking-pit and rolling-mill practices.

Work-Brittleness tests were made, as suggested by Graham and Work in *Proceedings*, A.S.T.M., 1939, p. 571, by drawing round tapered specimens through a die at room temperature, and making Izod impact tests at 45° V-notches cut 1.1 in. apart along the length of the bar. Two tapered bars of each sample were prepared in as-rolled condition, and two others after stress-relieving 3 hr. at 1100° F. One of each kind was tested by impact as soon as the notches could be cut after cold drawing, while the other one was aged three weeks at room temperature between cold drawing and impact testing, including one hour of accelerated aging at 450° F.

Results are reported graphically on Fig. 9, where each result is plotted against the strain, or per cent reduction of area by cold drawing, at the point on the tapered bar where that particular notch was cut. The curves in full line indicate the work-sensitivity of the steels in as-rolled condition, whereas the dashed lines represent the strain-aged specimens; the spread indicates susceptibility to strain-aging embrittlement.

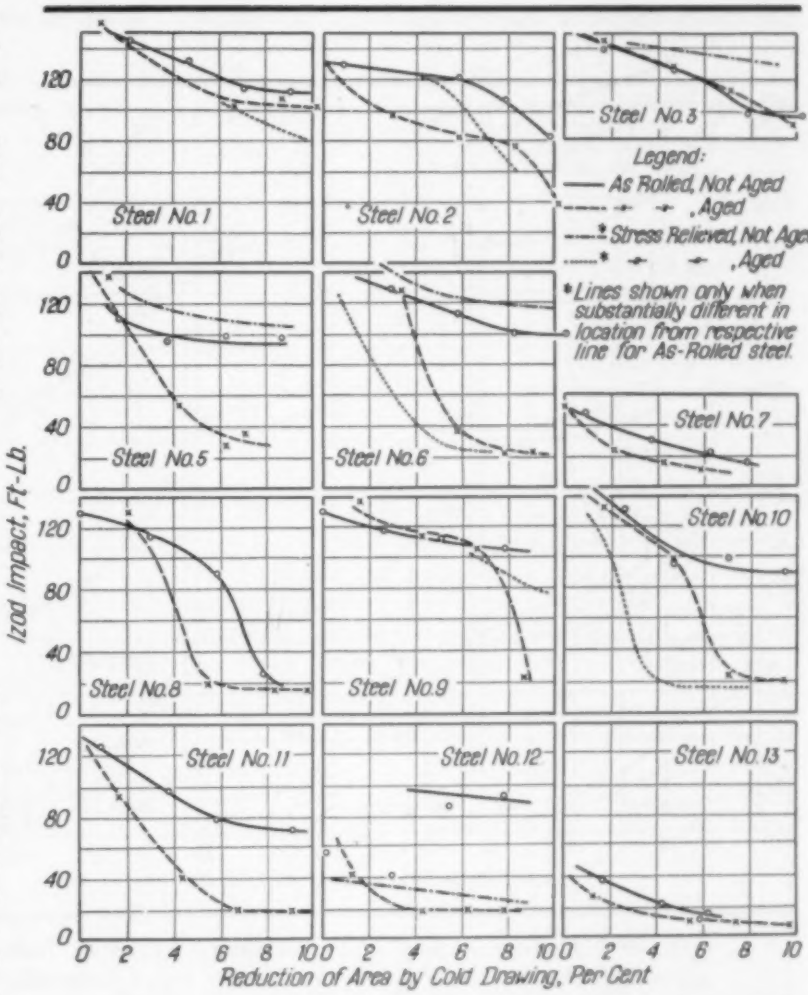


Fig. 9 — Work-Brittleness Tests. Steel No. 4 (omitted) gave results lower than for steel No. 13

The full lines and dotted curves of Fig. 9 show all the tests on steel in the condition as received, the test specimens either aged or tested as drawn. In the event that similar tests on the steels stress relieved before cold drawing were substantially different, they are shown in dash-dot and dotted lines for specimens tested immediately and after aging, respectively.

In general, stress relieving does not appear to change the type of diagram obtained for each steel. This establishes — at least to a reasonable degree — the reproducibility of the results.

Steel No. 4 was omitted from the chart, since all the work-brittleness impact results on it were very low, the curves being below those shown for steels No. 7 and 13.

The manganese-titanium steels No. 1, 2, 3 and 9 gave the best results in regard to both low work sensitivity and the minimum strain-aging embrittlement. The high manganese steel No. 7, and the high silicon steel No. 13 had such low impact values that the effect of strain-aging, if any, was hidden. The other manganese-titanium steels No. 5, 6, and 8 show considerable strain-aging embrittlement, and No. 8 also shows some degree of work sensitivity (drop in resistance with degree of cold work, before aging). The manganese-vanadium-titanium steels No. 10 and 11 are quite similar to No. 5 and 6. The manga-

nese-vanadium steel No. 12 gave irregular results in the condition as-rolled and not aged (note the two circles showing low impacts at zero and 3% reduction) but when stress-relieved or aged its notch-toughness was consistently low, as shown by the dot-dash line.

Thus in these tests, as in the Izod impact tests at different temperatures, the best results were obtained from the manganese-titanium steels containing not over 0.14% carbon and less than 0.035% titanium. According to these samples, vanadium does not seem to have had any beneficial influence on the notch-toughness or strain-aging embrittlement.

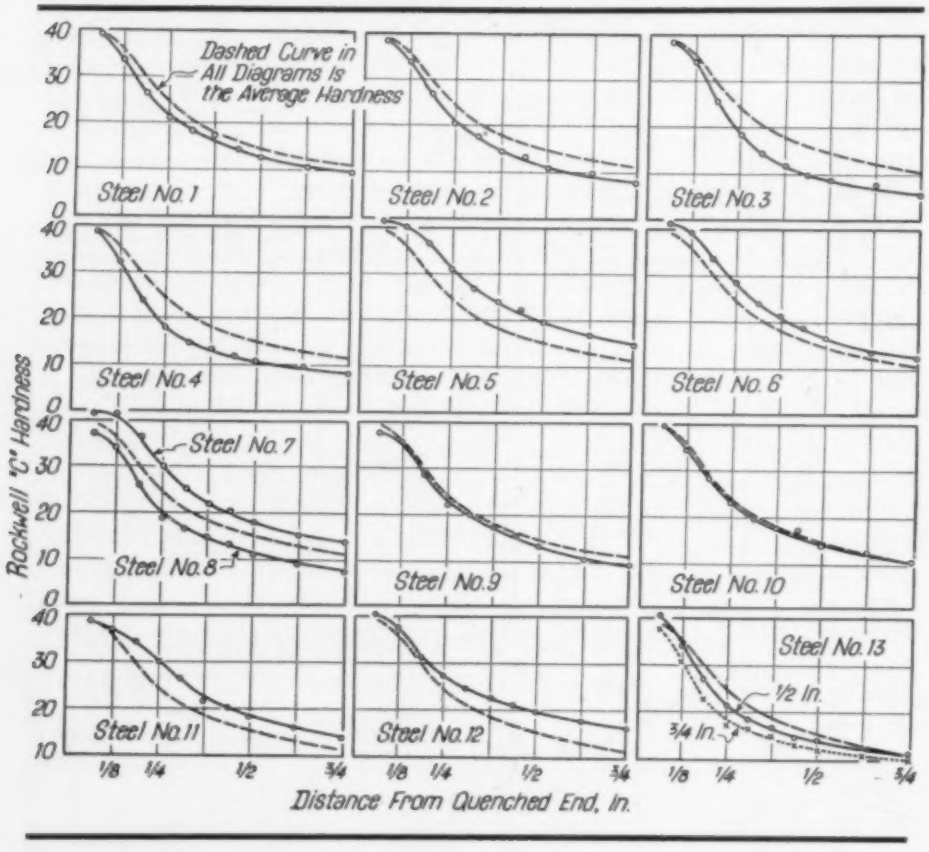


Fig. 10 — End-Quenched Hardenability Curves of Individual Steels as Compared With Average for All Samples

Hardenability tests were made by the Jominy end-quench method, using as-rolled specimens of ½-in. diameter with a ¼-in. water jet. Specimens were quenched from a temperature of 2100° F., and were protected from scaling at the quenched end. The results in the form of Rockwell C hardness values on flat surfaces carefully ground along the sides of the quenched specimens are reported graphically in Fig. 10. All of the separate diagrams in this chart include the same curve in the form of a broken line, which was plotted by averaging the hardness values of the respective points of all these 13 steels. By noting the relative position of this broken line and the full line representing the particular steel reported, it is easy to appreciate whether its hardenability is low, high, or average.

Two specimens were prepared from steel No. 13, which was received in the form of a ⅞-in. plate. One of them was of ½-in. diameter to compare with the other steels, and one was of ¾-in. diameter to approach more closely the standard size of hardenability test piece. The latter was end-quenched from 2100° F. with a water jet of ½-in. diameter. Results from both specimens are reported in Fig. 10, where it is evident that the ½-in. specimen was a little harder, although the inflection point of both curves is at practically the same distance from the quenched end.

According to the results of the hardenability tests, the manganese-titanium steels No. 1, 2, 3, 4, and 8 harden less deeply than the others, while No. 5, 6, and 7 are deeper hardening. This seems to be in fair agreement with the carbon and manganese contents as reported in Table I, especially in view of the higher copper, nickel, and molybdenum in steels No. 5 and 6. The low hardenability of the high titanium steel No. 4, which was lacking in ductility and notch-toughness, is worthy of note. The vanadium steels No. 11 and 12 are somewhat deeper hardening than the average, while No. 10 and 13 are not, although they also contain vanadium; the differences are roughly in accordance with the manganese contents, higher manganese generally promoting deeper hardenability.

Single-Bead Weld Tests — Pieces of each sample were cut 6 by 7 in., and weld beads were deposited transversely across them at a rate of 6 in. per min., using ¼-in. mild steel coated weld-

ing rods, with 225 amperes and 135 volts. (The ⅞-in. plate No. 13 was previously planed down to ½ in.) Scale was first ground off the surface before welding. No heating was applied either before or after, and each weld was air cooled in the same way.

Six strips, each ¾ in. wide, were cut transversely to the weld bead, or parallel to the direction of rolling, and notched in different ways for slow bend tests as discussed in later paragraphs. Smaller strips were also cut about midway between the two ends of the weld bead for hardness and impact tests.

Hardness surveys were made on two cross sections cut through each weld bead, ground smooth and etched to show the penetration of the fused zone. Four Rockwell A hardness tests were made just below that zone, to represent the maximum weld hardness. Four other tests were also made on each piece at a point remote from the heat-affected area and at the same distance below the surface of the plate, and averaged to show the original hardness of the steel. Hardening due to welding could then be determined by difference. The results are reported in Table IV.

Steels No. 4, 7, 10, and 12 hardened least, although this was due chiefly to the greater hardness of these samples *before* they were welded. The hardness *after* welding shows but little variation among these samples, and the variations are explainable in most instances on the basis of chemical composition, although there are some discrepancies.

Impact tests were made in duplicate on the same specimens used for the hardness tests. These specimens were machined to standard size for Charpy tests, with the weld penetration across the middle of one side. A 45° V-notch was cut 0.07 in. deep in the fused zone, so that its base was almost tangent to the boundary, but avoided penetration into the hardened zone below. The specimens were broken at room temperature in a Charpy machine with the notch in tension, 30 to 33 days after welding. Results are also reported in Table IV, alongside.

These impact results, like those in Table III for samples that were not welded, are lower for steels No. 4, 7, 12, and 13, although the vanadium steel No. 12 shows one high value in Table IV. The toughest welds occur in samples No. 1, 2, 3, 5, 8, and 11. Steel No. 9, which was so outstanding in low temperature notch-toughness, appears only moderately tough after welding. No. 6 also shows unexpectedly low values after welding.

Notch-Bend Weld Tests — On the same day that the weld beads were deposited, the two ¾-in. strips nearest the starting end of each bead were notched and tested for ductility by slow bending. On all but two of the samples, these notches were milled with ⅛-in. radius, and extended only as deep as the original surface of the sample — that is, through the "welt" of deposited metal. The other two, No. 9 and 10, were notched in accordance with the recommendation of Jackson and Luther in "The Bead-Weld Nick-Bend Test for Weldability", *Journal* of the American Welding Society, Oct. 1944, p. 523S, using a saw-cut 0.1 in. wide and extending through the bead to a depth of $\frac{3}{64}$ in. below the original surface of the plate.

Specimens were bent slowly, with the notch in tension, on supports 4 in. apart, using a plunger of ⅞-in. diameter to apply the load directly over the notch. Deflection was measured by a pivoted index giving a magnified scale reading. Deflection at maximum load was taken as the measure of ductility, but most of the bends were continued well beyond this to determine more definitely the character of the failure, or whether the crack would go straight across or be deflected lengthwise. Load-deformation diagrams were recorded on some of the bends, but they served merely to indicate a yield point, which seemed to be related more to the maximum load than to the deflection, and therefore to be of little value as a measure of weldability.

In addition to the above tests, made the same day as welded, two bend specimens cut near the

Table IV — Summary of Tests on Single-Bead Weld Specimens

No.	Type of Steel	Hardening Below Weld *(a)*				Impact, Notched Weld Specimens
		Hard Zone		Original Plate	Hardening	
		Max.	Average			
1	Mn-Ti	56.5	55.2	48.6	6.6	167; 208
2	Mn-Ti	54.	53.6	48.0	5.6	180; 153
3	Mn-Ti	53.	52.2	45.3	6.9	144; 154
4	Low Mn-Ti	57.	55.8	51.1	4.7	21; 20
5	Mn-Ti	58.	57.1	49.8	7.3	143; 128
6	Mn-Ti	56.	55.5	48.1	7.4	62; 58
7	High Mn-Ti	56.5	55.8	50.4	5.4	47; 46
8	Mn-Ti	54.5	53.8	47.6	6.2	135; 121
9	Mn-Ti	53.	52.4	46.2	6.2	82; 75
10	Mn-V-Ti	55.	53.8	48.6	5.2	77; 106
11	Mn-V-Ti	58.	57.2	49.3	7.9	152; 122
12	Mn-V	57.5	57.2	52.5	4.7	114; 43
13	Si-V-Ti	56.	55.8	47.8	8.0	33; 25

(a) Rockwell A scale.

Table V — Maximum Load (Lb.), Corresponding Deflection (In.) and Type of Failure of Notch-Bend Tests of Single-Bead Samples

No.	Type of Steel	Round Notch*; Tested Same Day				Saw-Cut Notch; Tested After 10 Days				V-Notch; Machined Bead; 5 to 6 Weeks Old			
		First Specimen		Second Specimen		First Specimen		Second Specimen		First Specimen		Second Specimen†	
		Load	Deflection	Load	Deflection	Load	Deflection	Load	Deflection	Load	Deflection	Load	Deflection
1	Mn-Ti	4610	0.99	4815	0.88	4370	0.70	4368	0.68	2833	0.65	2645	0.46
2	Mn-Ti	4350	0.98	4327	0.98	3952	0.76	3909	0.58	2652	0.43	2457	0.42
3	Mn-Ti	4600	1.25	4020	0.98	?	0.84	3630	0.70	2460	0.61	2350	0.35
4	Low Mn-Ti	4860	0.96	4700	0.81	4457	0.61	3942	0.37	2795	0.24	2759	0.29
5	Mn-Ti	4964	1.48	4830	1.39	4267	0.73	4110	0.65	2760	0.43	2395	0.28
6	Mn-Ti	4450	1.01	4503	0.95	4146	0.58	3890	0.55	2604	0.44	2713	0.35
7	High Mn-Ti	4570	0.56	5410	0.71	5130	0.59	5048	0.57	2636	0.27	2675	0.31
8	Mn-Ti	4410	0.90	4450	0.96	3945	0.67	4000	0.67	2671	0.50	2364	0.26
9	Mn-Ti	4210	0.61	4136	0.69	4332	0.76	4438	0.80	2528	0.43	2270	0.41
10	Mn-V-Ti	4600	0.62	4126	0.41	4782	0.69	4483	0.56	2652	0.32	2640	0.33
11	Mn-V-Ti	4526	1.02	4480	0.90	4340	0.77	4436	0.86	2815	0.46	2612	0.44
12	Mn-V	5193	0.98	5216	0.73	4800	0.52	4610	0.44	2900	0.49	2747	0.20
13	Si-V-Ti	4483	0.68	5000	1.05	4450	0.75	4220	0.60	2528	0.31	2436	0.28

No.	Type of Steel	Round Notch*; Tested Same Day				Saw-Cut Notch; Tested After 10 Days				V-Notch; Machined Bead; 5 to 6 Weeks Old			
		First Specimen		Second Specimen		First Specimen		Second Specimen		First Specimen		Second Specimen†	
		Load	Fracture‡	Load	Fracture‡	Load	Fracture‡	Load	Fracture‡	Load	Fracture‡	Load	Fracture‡
1	Mn-Ti	4610	S; D	4815	S; D	4370	S; D	4368	S; D	2833	S; D	2645	S; D
2	Mn-Ti	4350	S; D	4327	S; D	3952	S; D	3909	S; D	2652	S; D	2457	S; D
3	Mn-Ti	4600	S; D	4020	S; N	?	S; D	3630	S; D	2460	S; D	2350	Q; D
4	Low Mn-Ti	4860	Q; N	4700	Q; N	4457	S; N	3942	S; N	2795	Q; N	2759	Q; N
5	Mn-Ti	4964	S; D	4830	S; D	4267	S; D	4110	S; D	2760	S; D	2395	S; D
6	Mn-Ti	4450	S; N	4503	S; N	4146	S; N	3890	S; N	2604	S; D	2713	S; N
7	High Mn-Ti	4570	S; N	5410	S; N	5130	S; N	5048	S; N	2636	S; N	2675	Q; N
8	Mn-Ti	4410	S; N	4450	S; N	3945	S; D	4000	S; D	2671	S; D	2364	Q; N
9	Mn-Ti	4210	S; N	4136	S; N	4332	S; D	4438	S; D	2528	S; N	2270	S; N
10	Mn-V-Ti	4600	S; D	4126	S; D	4782	S; D	4483	S; D	2652	S; D	2640	S; D
11	Mn-V-Ti	4526	S; N	4480	S; N	4340	S; D	4436	S; D	2815	S; D	2612	S; D
12	Mn-V	5193	S; N	5216	S; N	4800	S; N	4610	Q; N	2900	S; D	2747	Q; N
13	Si-V-Ti	4483	S; N	5000	S; D	4450	S; N	4220	S; N	2528	Q; N	2436	Q; N

*Round notch except for steels No. 9 and 10 which had a saw-cut notch.
†Cut from crater ends of the weld and should probably be rejected.
‡As to type of failure, S means slow failure; Q means quick or sudden. As to type of fracture, N means normal or straight crack, as in steel No. 4 of Fig. 11; D means deflected crack, as in steel No. 5 of Fig. 12.

middle of the weld bead were notched by Jackson and Luther's saw-cut method and tested 10 days later. Two more specimens, all ¾ in. wide, were cut near the crater end of each bead, the beads planed flush, and machined on the side opposite the bead to $\frac{7}{16}$ in. thickness. They were notched by milling the fused zone with a 45° V-cut, 0.06 in. deep, so as to penetrate not quite to the boundary of that zone.

These specimens were tested in the same way as the others. The results obtained from the specimens cut at the crater ends of the welds were in most instances lower, respectively, than those obtained from the other specimens and probably should be rejected. All these results, however, are reported in Table V.

The saw-cut notches, being deeper than the round notches, gave in general lower deflections and the V-notches, of course, still lower. Jackson and Luther's report that welds improve in ductility a few days after welding is supported by the data on steels No. 9 and 10, where with the same type of notch higher deflections are reported 10 days after welding than on the day when the welding was done.

An idea of the significance of the data in Table V can be obtained more readily from the following summary of deflections:

Steels With Round Notches
One value less than 0.85 in.: No. 4, 7, 12, 13
Both values above 0.95 in.: No. 2, 3, 5, 6

Steels With Saw-Cuts
One value less than 0.60 in.: No. 2, 4, 6, 7, 10, 12
Both values above 0.65 in.: No. 1, 3, 5, 8, 9, 11

Steels With V-Notches
(omitting the crater specimens)
Values less than 0.40 in.: No. 4, 7, 10, 13
Values above 0.48 in.: No. 1, 3, 8, 12

The low manganese, high titanium steel No. 4, and the high manganese steel No. 7, are definitely inferior in weldability by this method of testing, but the other manganese-titanium steels No. 1, 2, 3, 5, 6, 8 and 9 are, in general, the best. The manganese-vanadium-titanium steels No. 10 and 11 are moderately good. The vanadium steel No. 12 gave variable results, as in the work-brittleness tests, showing up well when V-notched, but rather poorly otherwise. The silicon steel No. 13 was also variable, but in most instances it cracked more readily than the others.

A selection of some typical failures obtained in these tests is illustrated by Fig. 11 and 12. Specimens No. 4, 12, 13, and the

Fig. 11 — Typical Notch-Bend Specimens of Single Bead Welds, Notched by Sawing, After Bending Beyond Maximum Load, to Show Type of Fracture. Natural size

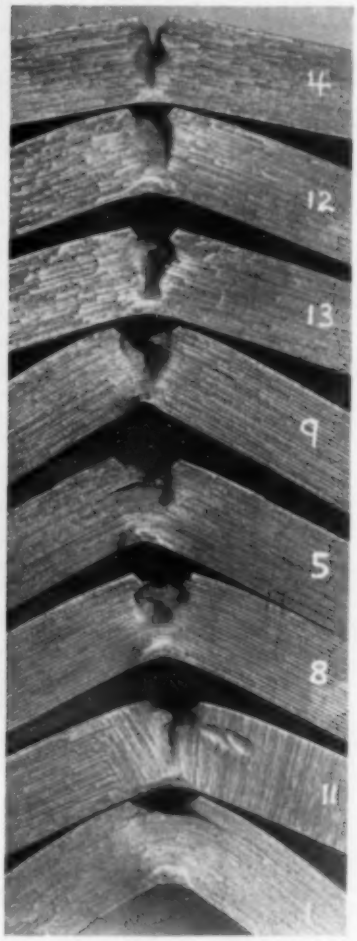


Fig. 12 — Representative Samples, Milled Smooth and Cut With V-Notch

V-notched No. 9 show what were classified as normal or straight cracks in Table V, while the others exhibit deflected cracks. Most of the weld bend specimens were bent well beyond the point of maximum load and the bend angles in the photographs therefore do not agree with the deflections at maximum load reported in Table V.

It is interesting to note that the results of these weld ductility and cracking tests have practically no correlation with the weld-hardening results of Table IV or the hardenability curves of Fig. 10. It seems that the latter methods are of no value, and may even be misleading, as indications of weldability, if this term is taken to imply the maintenance of toughness and ductility under a weld deposit. Notch-bar impact tests seem to give a better idea of the results to be expected in welding, or of the suitability of a steel for welding, where notches of some form may not always be completely avoided.

General Comparison of the Different Steels — The data reported bring out clearly the undesirability of a titanium content as high as 0.05% (as in steel No. 4) at least with low manganese and as much as 0.24% chromium in steel to be used in the as-rolled condition. The amount of titanium and chromium liable to occur in solution in the ferrite of such steel not normalized may cause a dangerous degree of notch sensitivity. In summarizing the results to compare the different classes of steel represented by these samples, steel No. 4 is therefore neglected.

Steel No. 7 is likewise rejected, since its manganese content is above the permissible limit for the Navy high-strength plate, and its properties justify the enforcement of a lower limit for manganese. The silicon steel No. 13 also seems of less interest than the other grades, possibly because its titanium and vanadium contents are high enough to bring it into the same class as steel No. 4, although the mere fact that this steel was rolled thicker than the others would account for its less desirable properties.

Table VI is a summary of the data pertaining to the other classes of steel considered in this report, namely manganese-titanium with 0.024 to 0.035% titanium, manganese-titanium with 0.013 to 0.018% titanium, manganese-vanadium-titanium with 0.015 to 0.023% titanium and 0.02 to 0.04% vanadium, and manganese-vanadium with 0.087% vanadium. It will facilitate a comparison of average results derived from all the tests described above. Since these steels are intended for use in the as-rolled condition, only the specimens tested in that condition are included in the averages.

The compilation of average results in Table VI indicates slightly lower strength and generally

higher ductility and impact resistance, both as-rolled and as-welded, for the higher titanium steels. However, the differences between this class and the lower titanium steels are slight, and may be largely accounted for by the difference in the range of carbon contents. It may be concluded that both classes of steel are satisfactory in the as-rolled condition for high strength weldable plates, with the lower carbon, higher titanium grade averaging a little better in notch-toughness, resistance to aging, and weldability.

Probably not enough vanadium steels were included to warrant any conclusions regarding the manganese-vanadium types. The occurrence of 0.04% or less vanadium in the low titanium steels No. 10 and 11 does not appear to have affected their properties materially, and certainly cannot be held to have produced any improvement in the results of our tests. The plain manganese-vanadium steel No. 12 was stronger than any of the other steels, and shows less weld hardening, but in most of the other tests it seems to be somewhat inferior. Perhaps with lower manganese or copper, and lower strength, Mn-V steel might be more comparable to Mn-Ti steel in ductility, weldability and resistance to impact and aging.

The chief conclusion to be drawn from this investigation is that the excellence of manganese-titanium steel in the form of weldable high-strength plates, as reported in December for laboratory-melted steels in *Metal Progress*, is confirmed by tests of a number of commercial plates. The acceptable range of titanium content for best results with commercial steel may not be exactly the same as was arrived at from the laboratory melts. From the present work 0.057% titanium seems to be too high for notch-toughness and weldability unless the steel is normalized to lessen the amount of titanium in solution in the ferrite (although the presence of chromium in the high titanium steel renders this conclusion somewhat uncertain). For plate to be used in the as-rolled condition the preferred titanium content is probably about 0.02 to 0.04%, with 0.13 to 0.15% carbon and 1.15 to 1.30% manganese.

Manganese as high as 1.59% should certainly not be permitted in weldable plates, and chromium above about 0.10% may also be undesirable. Commercial plate steels with 0.14 to 0.17% carbon, 1.25 to 1.35% manganese, and 0.01 to 0.02% titanium are shown to be satisfactory in strength, ductility and weldability, however, and only slightly inferior to the higher titanium type in notch toughness and resistance to aging. Contrary to the results obtained from the laboratory melts, this lower titanium commercial steel is now found superior to commercial manganese-vanadium steel (or at least to the heat available for this investigation) in ductility, notch-toughness, weldability, and resistance to aging.

The addition of 0.02 to 0.04% vanadium to the low titanium grade of manganese-titanium steel did not seem to improve any of the useful properties appreciably, but neither was it detrimental. The manganese-vanadium steel with 0.087% vanadium, however, was definitely stronger than the manganese-titanium grades, and showed less weld-hardening; otherwise, as noted above, its properties were inferior. This should no doubt be checked with other heats before drawing general conclusions.

Table VI — Average Results for Four Classes of Steel

½-in. plates, as-rolled, test specimens cut parallel to direction of rolling

	Mn-Ti No. 1, 2, 3, 8	Mn-Ti No. 5, 6, 9	Mn-V-Ti No. 10 & 11	Mn-V No. 12
Chemistry range				
Carbon, %	0.13-0.14	0.14-0.17	0.14-0.15	0.15
Manganese, %	1.17-1.31	1.25-1.34	1.11-1.29	1.13
Titanium, %	0.024-0.035	0.013-0.018	0.015-0.023	None
Vanadium, %	None	None	0.02-0.04	0.087
Hardenability				
Depth to C-30, in.	0.16	0.22	0.21	0.20
Tensile properties				
Yield point, psi.	51,100	53,700	52,800	59,000
Tensile strength, psi.	72,350	78,600	76,700	85,600
Yield ratio, %	70.7	68.4	69.0	68.9
Elongation in 2 in., %	32.9	30.2	32.2	24.0
Reduction of area, %	71.4	70.3	67.2	68.4
Impact values in ft-lb.				
At 70° F.	161	141	137	58
At 32° F.	134	83	56	12
At −30° F.	6	50 *(a)*	5	3
Strained 2%	134	121	125	(?) 55
Strained 8%	86	100	81	88
Strained 8% and aged	76	42	20	16
Welding tests				
Weld hardening *(b)*	6.3	7.0	6.5	4.7
Impact value, ft-lb.	158	108	114	79
Weld bend deflection				
Round notch, in.	0.99	1.02	0.96	0.86
Saw-cut notch, in.	0.70	0.68	0.72	0.48
V-notch, in.	0.55	0.43	0.39	0.49

(a) With the high values for sample No. 9 omitted, this average would be 6. *(b)* In Rockwell A-scale hardness units.

Lengthen Service Life

...regardless of unit size!

4 TIMES LONGER LIFE

Eight years' service instead of two, was obtained by a large chemical company through specifying Nickel cast iron in this 8-ton ring. Plain iron used here corroded and eroded ½" per year. This Nickel alloyed iron wears less than ⅛" in the same time.

Increases Result/Dollar Ratio...

In products and applications . . . from a wrench to a railroad . . . records show that a little Nickel goes a long way to lengthen product life, to reduce bulk and deadweight, and to save maintenance costs.

When compared with costs involved, metals to which Nickel is added invariably rise sharply in service value . . . due to improved performance.

Nickel imparts strength, hardness, toughness, resistance to corrosion, heat and abrasive wear. In all fields of industry Nickel offers significant advantages. Send us details of your problem for our recommendations.

THE INTERNATIONAL NICKEL COMPANY, INC.

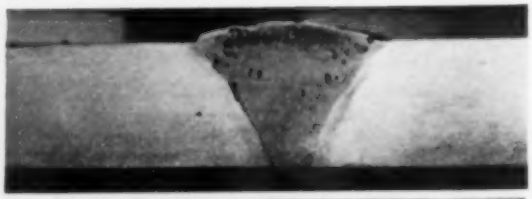
67 Wall Street, New York 5, N.Y.

March, 1945; Page 520A

Arc-Welding Troubles and Their Cures

Sheet 2 of 2.

Westinghouse Electric & Mfg. Co.



Porous Welds

Causes: A—An inherent property of some "electrodes". B—Not sufficient puddling time to allow intrapped gas to escape. C—Gassy base metal. D—Too short an arc length.

Cures: A—Be sure the proper electrodes are used. B—Puddling keeps the weld metal molten longer and often insures soundness. C—A weld made of a series of strung beads is apt to contain minute pinholes. Weaving will often eliminate this trouble. D—Avoid excessive welding currents. E—Check base metal by a simple bead run with an electrode known to be first class. F—Lengthen the arc.

Poor Surface Appearance

Causes: A—Improper current and arc voltage. B—Overheated work. C—Poor electrode manipulation. D—Inherent characteristic of electrode used.

Cures: A—Use proper welding technique for the electrode in hand. B—Avoid excessive welding currents. C—Use a uniform weave or rate of travel at all times. D—Prevent overheating of the work.

Incomplete Penetration

Causes: A—Improper preparation of the joint. B—Too large an electrode. C—Insufficient welding current. D—Too rapid a welding speed.

Cures: A—Allow the proper free space at bottom of the weld. B—Do not expect excessive penetration from the electrode in hand. C—Select small diameter electrodes for a narrow welding groove. D—Use sufficient welding current to obtain proper penetration. Do not weld too rapidly.

Poor Fusion

Causes: A—Improper diameter of electrode. B—Improper welding current. C—Improper preparation of the joint. D—Improper welding speed.

Cures: A—When welding in narrow vees, use an electrode small enough to reach the bottom. B—Use sufficient welding current to deposit the metal and penetrate into the plates; heavier plates require higher current for a given electrode than light plates do. C—Be sure the weave is wide enough to melt, thoroughly, the sides of the joint. D—The deposited metal should tend to sweat onto the plates and not curl away.

Excessive Corrodibility of Bead or Metal Alongside

Causes: A—Wrong type of electrode used. B—Improper weld deposit for the corrosive medium to be resisted. C—Metallurgical effect of welding. D—Improper cleaning of weld. E—Porosity and slag inclusions. F—"Non-stabilized" base metal (stainless steel).

Cures: A—Change from bare electrode to properly covered electrode. B—Use shielded arc-type electrodes. C—Select electrodes which have excess of easily oxidizable alloys, so weld deposit matches the chemical composition of the base metal. D—Avoid slag inclusions and gas porosity by all available means. E—Excessive corrosion alongside weld, often experienced in "austenitic" stainless and corrosion resistant steels, is avoided either by using base metal and electrodes "stabilized" by alloying with a little columbium, or by quenching the completed weldment rapidly from 2000° F.

Warping of Thin Plates

Causes: A—Shrinkage of deposited weld metal. B—Excessive local heating at the joint. C—Improper preparation of the joint. D—Improper clamping of parts.

Cures: A—Select electrode with high welding speed and moderate penetrating properties. B—Work rapidly to prevent excessive local heating adjacent to the weld. C—Avoid excessive spaces at joints. D—Properly clamp parts adjacent to the joint. Use back-up to cool parts rapidly. E—Use special welding sequence such as step back or skip procedure. F—Peen joint edges slightly before welding to elongate them and counteract the weld shrinkage.

Spatter

Causes: A—An inherent property of some "electrode" types. B—Excessive welding current for the type of electrode, or for its diameter. C—Excessively long arc. D—Arc blow.

Cures: A—Select proper type of electrode. B—Reduce the welding current. C—Hold proper arc length. D—Reduce arc blow. E—Paint parts adjacent to weld with whitewash, which prevents prills from sticking, and they can then be brushed off easily.

METALS FOR RAILROADS

How Rail Failures Are Being Prevented

By R. E. Cramer
Special Research Associate Professor
University of Illinois
Urbana, Illinois

"A research typical of the very best that can be done, and one of tremendous value to the railroads of America." This is the appraisal of the rail investigation at Urbana, which was made by A. G. Trumbull, Chief Mechanical Engineer to the Advisory Committee of the Chesapeake & Ohio Railway Co. and its associated railroads, acting as summarizer of the group discussion on "Metals for Railroads" at the last ⊜ Convention. Professor Cramer, who gave the following brief talk to this group on "How Rail Failures Are Being Prevented" is eminently qualified, for he has been studying the fissure problem for 14 years, one of the men of this Urbana group who have been investigating rails under the joint auspices and direction of the Rail Manufacturer's Technical Committee and the Association of American Railroads.

IN ORDER TO APPRECIATE modern rail manufacturing practices, we must consider some of the difficulties formerly encountered in service. Probably the most disturbing and dangerous type of defect to develop in rails was the internal transverse fissure such as shown in Fig. 1. This defect was described and named in 1912 by James E. Howard, then chief inspector of safety appliances for the Interstate Commerce Commission. This type of failure was studied individually by many railroad engineers and metallurgists for the rail mills from its first discovery.

Lacking any agreement as to cause or remedy the best that could be done was to remove fissured rails as fast as they could be discovered. Fortunately the detector car came into use in 1928, a device which can discover sub-surface defects while travelling over the track, by registering the differences in the electrical properties (the Sperry type car) or in magnetic properties (the A.R.E.A. type car) of the rail at a dangerous defect. About 20 Sperry cars are now in constant use, and about eight of the A.R.E.A. magnetic type.

In 1931 a joint investigation of the causes and methods of prevention of transverse fissures was started at the University of Illinois under the direction of Professor H. F. Moore. The contract for this work covered a five-year period and it worked out that this was about the time necessary to determine the best cure for the fissure problem, and for all American rail mills to install equipment to handle their production. Summaries of the findings of the research committee have been published at intervals in *Metal Progress*.

It was found in rolling load tests at the University laboratory that transverse fissures could be developed only in rails which contained shatter cracks (see Fig. 2). It happened that I. C. Mackie at the Dominion Steel & Coal Corp., Sydney, Nova Scotia, started a separate investigation of methods of preventing the development of shatter cracks in 1931. By December of that year, he had developed a commercial process of control-cooling rails which solved the problem. It was announced in an editorial article "Overcoming Shatter Cracks in Rail Manufacture" in *Canadian Chemistry and Metallurgy*, Vol. 16 (1932), page 141.

Mr. Mackie's process was adopted after much experimentation by the United States rail mills in 1935 and 1936, and since that time about 8,000,000 rails have been produced yet only two control-cooled rails have developed transverse fissures from shatter cracks, as noted in the last line of the general table shown on page 522. Investigation disclosed that these rails were in the top layer of a cooling container which had a very loose fitting lid and so were not properly cooled. It was also found that control-cooling prevents most of the horizontal and vertical split head

Fig. 1 — Transverse Fissure Starting From a Shatter Crack

failures (Fig. 3) which previously have been about as numerous as failures from transverse fissures.

The control-cooling is simplicity itself. Since the temperature zone at which shatter cracks are produced is relatively low, the rails can cool on the hot bed through the critical range, and thus become magnetic and can be handled with magnets. Only reasonable speed in getting them into a cooling pit is necessary; some 150 to 200 hot rails are loaded into the pit, the pit is covered, and the rails cool slowly. That's all there is to it. If floor space for cooling pits is unavailable in a congested mill, a lot of gondola cars can be lined with insulating refractories, and tight fitting covers constructed, thus becoming movable pits.

A part of the writer's work for the last several years has been the examination of control-cooled rails which have failed in service. (It is undoubtedly true that the old statistics are inaccurate inasmuch as there was no uniform practice, road to road, as to just what should be classified as a transverse fissure.) So far 91 have been examined and the failures classified thus:

Detail fractures from shelly spots	27
Transverse fissures from porosity	24
Split webs	14
Detail fractures from wheel burns	8
Shelly spots only	4
Transverse fissures from welded spots	3
Horizontal split heads	3
Vertical split heads	2
Detail fractures from head checks	2
Crushed heads	2
Transverse fissures from shatter cracks	2

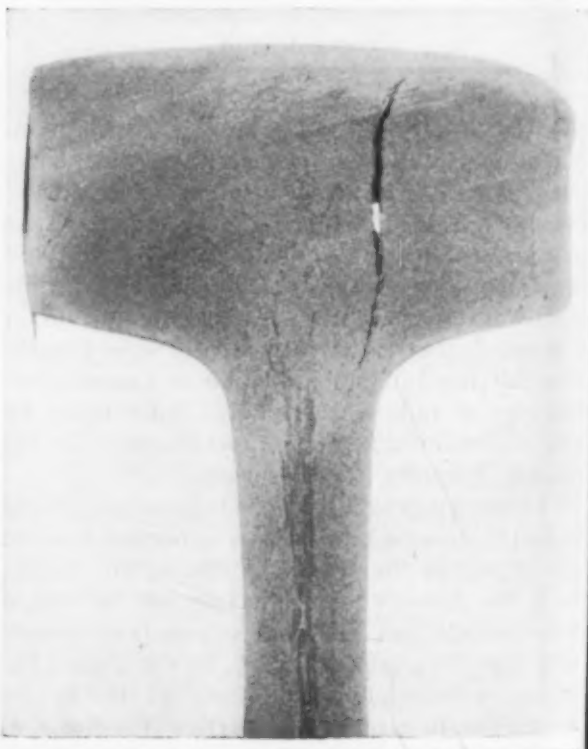


Fig. 3 — Vertical Split Head. This type of failure often develops from a longitudinal shatter crack normal to the running surface

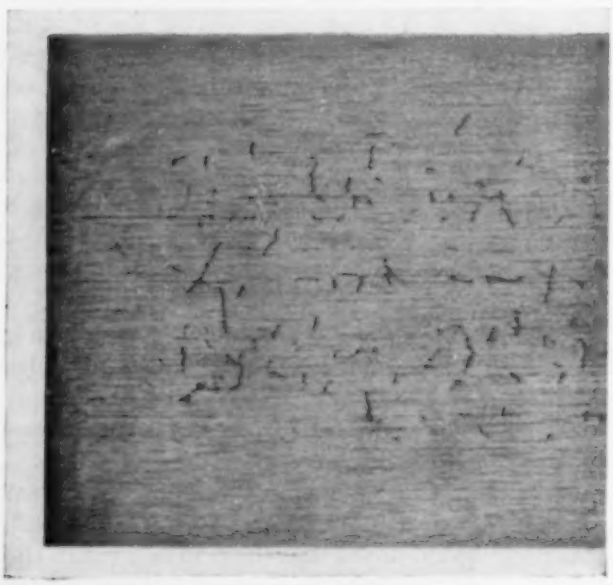
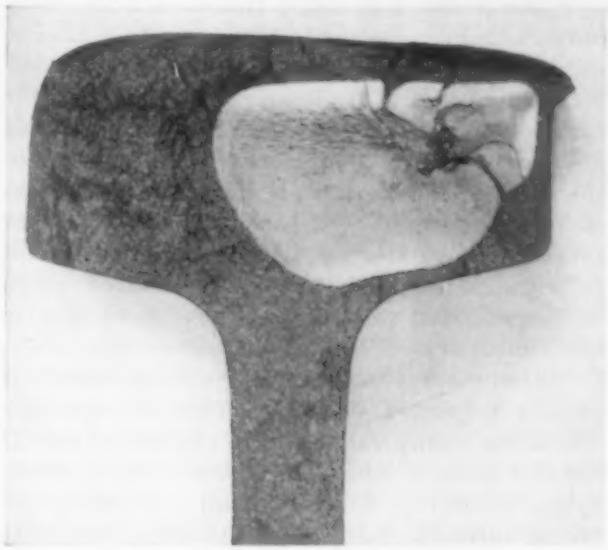


Fig. 2 — Shatter Cracks in Slice From Rail Head; Etched in Hot 50% Hydrochloric Acid

Fig. 4 — Transverse Fissure From Porosity Caused by Burning of the Bloom Before Rolling the Rail



It will be noticed that 24 rails have developed transverse fissures from porosity. A typical example is shown in Fig. 4. The problem of eliminating such porosity has been investigated by some mill metallurgists and it has been found that one cause can be the "burning" of the blooms while they are being reheated for shaping into rails.

The problem of split webs (see Fig. 5) has been given serious study by several groups of engineers and it has been found that most of these failures are caused by spike maul blows on the side of the web opposite where the crack

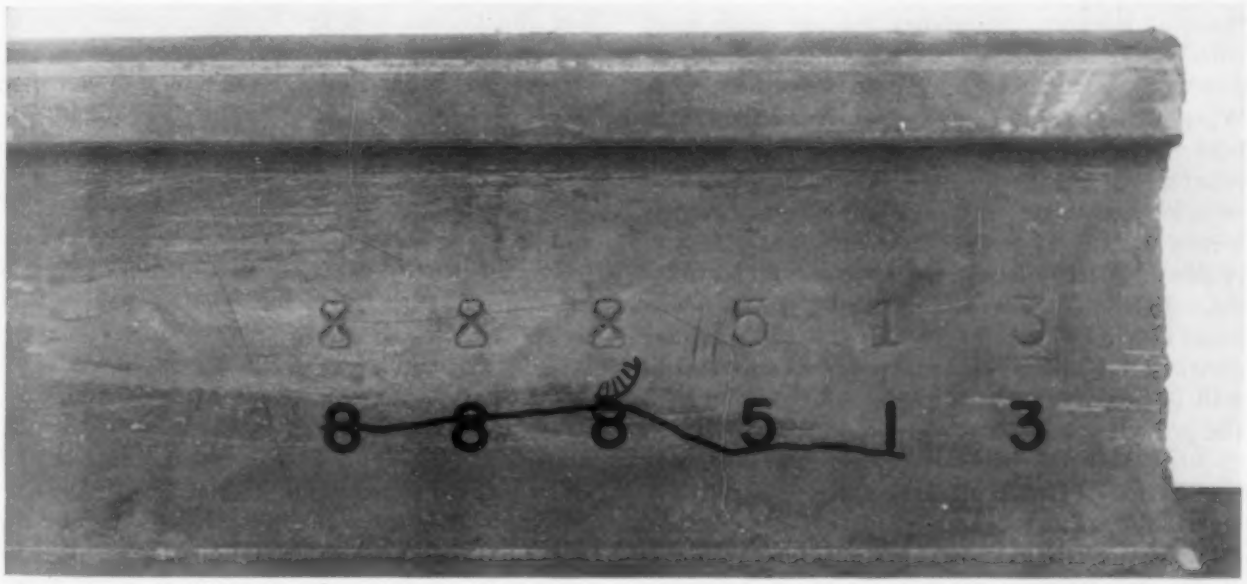


Fig. 5 — Split Webs Caused by Spike Maul Blow. The maul struck just above the 8; numbers, maul dent, and crack have been reproduced in ink

Fig. 6 — Detail Fracture From Shelly Spot. A portion of the gage corner has been sawed out to show both the horizontal shelling crack and the transverse detail fracture

starts. Rail steel in the webs seems to be quite sensitive to such blows at temperatures below 25° F. Until recent years it was not customary for railroads to lay rails in cold weather, so this difficulty can be considered to be a war problem because in recent years the railroads have had to lay rails at any time they could get them rolled.

The problem of detail fractures from wheel burns is being investigated by laboratory studies conducted by the Southern Railroad. In the meantime, several railroads have adopted the practice of welding up wheel burns before they have an opportunity to develop fatigue cracks in the rails. All reports indicate that this process is quite successful — at least it is a satisfactory measure to use during the war period. As will be seen in the table only three failures which developed from welded spots have been sent to the University of Illinois laboratory for study.

There are two types of failures which at present present a serious problem to railroads. These are shelly rail failures (including the 27 detail fractures which developed from shelly spots, as in Fig. 6), and detail fractures from "head checks". Laboratory investigations have been underway for about three years to determine a satisfactory kind of rail steel to resist these types of failure. It appears that an alloy steel with properties equivalent to a 3% chromium, 0.30% carbon rail steel described by George B. Waterhouse in *Metal Progress* in April 1934, or a heat treated carbon steel rail will be required to satisfactorily prevent these types of failures in certain track locations, such as on sharp curves where wear is so severe that the track normally is oiled. Such rails will be much more expensive than the standard carbon steel rail. So far a few heats of the 3% chromium rails have been placed in track for observations, but no American rail mill is prepared to furnish heat treated rails at the present time.

In conclusion it may be stated that control-cooling has solved the major portion of rail failures which occurred during the first five years of their service. Some new types of failures such as shelly rail failures are still being investigated, and it is believed that a considerable change in rail properties will be necessary to avoid them.

Detection and Prevention of Incipient Cracking in Firebox and Boiler Steel

By Ray McBrian
Engineer of Standards and Research
Denver & Rio Grande Western R. R. Co.
Denver, Colo.

ANY DISCUSSION of the subject of detection and prevention of incipient failures in firebox and boilers will get into a consideration of fatigue failures, for it should be realized that in service the boiler and firebox undergo a severe stress cycle each time the locomotive is fired, and that stress cycles occur from drifting operations — as by the feed water passing over the hot metal intermittently — from momentary temperature and pressure variations in normal operation on the road, and from the cool-down operations in washing the boiler. Aside from true fatigue failures these service stresses — at associated temperatures — greatly influence the life of the materials and contribute to the causes for incipient failures.

The types of materials used for locomotive boilers are the plain carbon steels, the so-called silico-manganese, the nickel steels, and the carbon-molybdenum steels. Records to date indicate that there have been service failures in all these materials; no one material has been found which will meet all of the service requirements and eliminate failures. This means that the maintenance crew must be constantly on the alert, and the boiler must be carefully inspected with the most searching means at command, at safe intervals.

These complex failures in service may be from aging or embrittlement, from fire cracking, corrugation, corrosion fatigue, fatigue from fabrication stress raisers, and from

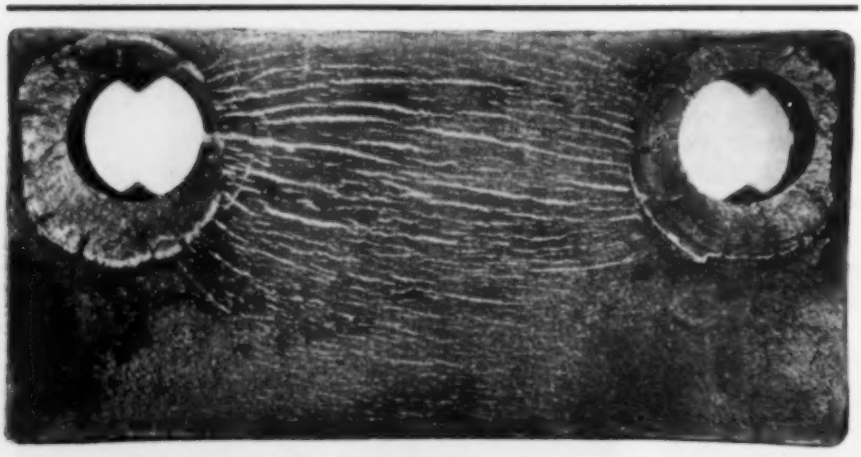


Fig. 1 — Fire Cracking Between Staybolts, Found by Magnaflux

Denver & Rio Grande Western Railroad has an enviable position among the Class I railroads for its very low number of engine failures on the road. It is primarily due to insisting on an iron-clad rule: "Nothing runs with a crack." The next thing after discovering incipient failures before they make trouble in traffic is to find some means of preventing them. Ray McBrian heads up a department which has been very successful in just that, and in this contribution discusses the most prolific cause of trouble in locomotive boilers and fireboxes.

improper composition of materials and their insufficient properties at elevated temperatures, especially in the so-called blue brittle range. Let us discuss some of these briefly.

Aging — The phenomenon of "aging" of steel has been and is the subject of much study. It seems to me that such terms as "strain aging", "carbon aging", "temper brittleness", and "blue heat brittleness" are used to designate substantially similar *effects*. To us in a railroad's research department, aging simply means that phenomenon which occurs under service conditions leading to brittleness and subsequent failure and recognizable by a loss in elongation and reduction of area normal to the material in its original condition when tested in the standard tension test. Thus the fact that aging is taking place in metal, even before failure, is determined by the tensile test on material removed from service. The expected performance of material which may age in service can also seemingly be predicted by making tension tests at elevated temperature. When the yield point and tensile strength is plotted against temperature of test, those materials which show a rapid rise or a high peak in the blue brittle range (350 to 650° F.) can be expected to "age" in locomotive boiler service. Rimmed steel seems to be very susceptible to aging.

Fire Cracking — Another of these boiler troubles is what is called fire cracking (Fig. 1). The explanation of fire cracking seems to be that when steel is heated from room temperature to 1000° F., it lengthens by approximately seven parts per thousand. If it is restrained from lengthening, as in a locomotive firebox rigidly held by staybolts, it must upset itself by compression or free itself to move in some other way. As a matter of fact a locomotive firebox sheet under 200-lb. pressure is at a variable temperature of from 380° F. on the water side to a skin temperature on the fire side of approximately 1000° F. Therefore, the fire side tends to expand more than the water side, and the sheet tends to bow out between the restraining staybolts. Even this does not relieve all the compression stresses, since the yield strength of the fire side skin is low at the temperature it attains. Under any of these conditions the fire side tends to upset or shorten at heat, and on cooling again the fire side surface is in heavy tension in all directions, and the surface tends to crack just as does an overstressed tensile specimen. Obviously, also, the cracking will develop faster in a sheet having a decarburized surface, for strength is directly proportional to carbon content. This action therefore develops fatigue cracks of a nature which can be identified by a gingerbread appearance. The condition of the surface skin, or rather the depth of decarburization, also influences the tendency to crack both on the fire side and water side.

These cracks between staybolts can be detected in their earlier stages by magnaflux, and later by visual inspection. They can and do occur in the absence of leaks.

One of the solutions for this problem has been through the use of carbon-molybdenum steel, where 0.50% molybdenum is relied upon principally to strengthen the ferrite (decarburized) surface. Obviously another palliative or cure is to correct the circulation to relieve the so-called hot spots.*

Corrugations — Associated with the temperature effect is the problem of corrugations. Corrugations can be described as large deformations due to stresses occurring during firing, stresses which are too much for the low physical strength of the material at operating temperatures.

The danger from corrugations is that scale can accumulate in the depressions, and result in serious overheating. Our solution to this problem is to use a carbon-molybdenum steel which supplies the added strength necessary at operating temperatures.

Staybolts — With these problems of the firebox material are associated similar ones of the staying material, the staybolt. Materials generally used by the railroads for this service are double refined wrought iron, and steel.

*In discussion it was brought out that, from a "practical" standpoint, trouble begins when the staybolts begin to leak. The round-house boiler makers then head up the bolt, and from time to time the same thing occurs until there is no longer a head on the staybolt, and then the side sheets begin to fail. Consequently a steel is needed that will resist some of the abuse it gets in ordinary maintenance. The speaker believed that such a steel would also have improved properties at operating temperatures.

Fig. 2 — Crack in Boiler Caused by Reamer Marks in Rivet Hole

With steel staybolts, failures can occur from aging. This is usually found by the boiler inspector when, upon tapping the head of the staybolt, it breaks, sometimes like glass. Physical tests then confirm the aging. Decarburized surfaces of steel staybolts also result in progressive fatigue cracks and rapid crack propagation, especially if the boiler water is corrosive and aging is present. Some investigators would call this stress corrosion.

Brittle breakages have occurred in wrought iron staybolts, and upon micro-examination nitride needles have been found in the structure. This nitrogen content, we believe, was the contributing cause of failure. With both the steel and wrought iron staybolts, fatigue failures occur in the threaded area, usually starting at the root of the thread. There is need for further study of threaded materials and of means to reduce stress concentrations at such "notches".

Staybolt breakage has been greatly reduced on D. & R.G.W. locomotives by the use of molybdenum wrought iron. We have not had a broken radial bolt from this material in the last four years.

In boilers, as well as in fireboxes, fabrication practices are most important as contributing causes for failure. Especially is this true since our materials are operating in the blue brittle range; associated with the problem of stress raisers is, therefore, that of temper brittleness.

Rivets — Along with the failure of boiler sheet materials is the failure of rivets. Many interpret rivet failures as evidence of caustic or intergranular corrosion; however, another cause can be temper brittleness or a brittle condition left in the rivet either after cold or hot working. This brittleness can also come from too low a carbon content; some rivets have been found which border on ingot iron.

In summary, boiler shell failures can occur from a combination of service stresses, stress raisers and temper brittleness of the material. In addition to this type of failure is that of the intergranular type, "caustic embrittlement", so-called, of which we have had very little in locomotive boilers on our road.

From service records available, alloy steels appear to be more susceptible to notch sensitivity and rapid crack propagation, than plain carbon steels are. Consequently some railroads have foregone the possibilities of weight reduction by continuing the use of plain carbon steel rather than the stronger alloys. We need to learn more about the notch sensitivity of alloy steels, especially under operating temperatures, and we must

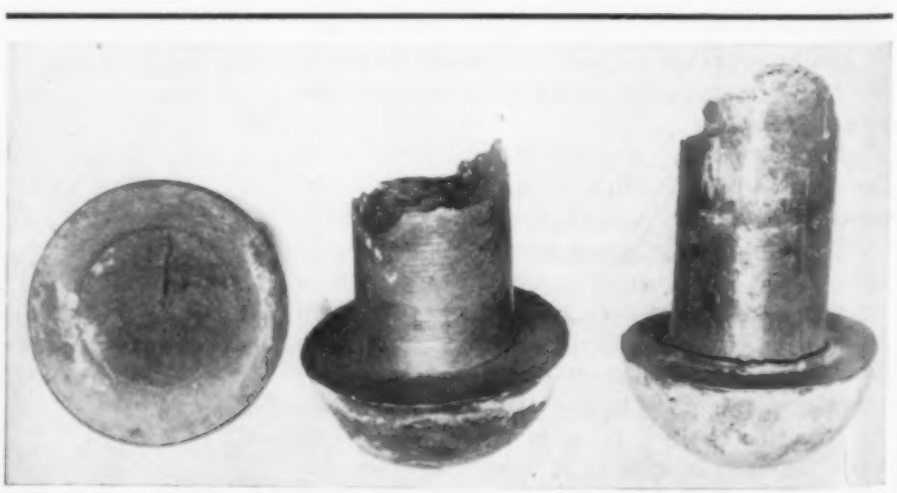


Fig. 3 — Cracked Rivets Resulting From Improper Driving Temperatures Which Left Them in Highly Stressed or Embrittled Condition

insist that fabricators give more care to the handling of alloy materials.

Inspection — Radiographs, using either radium or X-ray, can be utilized for the detection of cracks in boiler seams. Radium is portable and can be easily adapted to the job in hand. Magnaflux methods can also be used both for the detection of surface cracks in the boiler and firebox materials, and also for the detection of laminations in plates exposed in drilled holes and along the edges.

Thermoflux methods for measuring heat dissipation through a sheet can detect laminations in plates. This same method, using coatings which change in color at various temperatures, can also be used to detect laminations or badly segregated areas.

Recommended Good Practices

In general, it may be said that in the future construction of locomotives, fully killed steel should be utilized in all firebox and boiler materials. Steels with decarburized surfaces should be avoided, even though the fire side sheets operate under conditions that normally would decarburize the surface slightly. In specifying constructional materials, designers must recognize the properties of the materials *at the actual operating temperatures*. Fusion welding of boilers (with proper stress relief) will eliminate the so-called caustic or intergranular type of failure.

Modern inspection methods using X-ray, radium, magnaflux, and thermoflux may be employed to detect failures in boiler and firebox materials, and prevent breakdowns on the road, or even fatal accidents.

Such steps are the more necessary when it is appreciated that boiler, firebox, crownsheet and staybolts are usually made of substantially the same materials as they were 70 years ago, yet the boilers are operating at 100 to 150° higher temperature, about four times the pressure and evaporating at least ten times as much water per hour as did the early locomotives. It does little good to fall back upon the thought that the doctors do not yet agree upon the cause of failures in fireboxes and staybolts, nor to argue with the mechanical and maintenance engineers as to whether the trouble is due to poor design or to poor steel or to poor maintenance. It may not be out of place, however, to point out the fundamental error of punching holes and threading them, thus introducing serious stress raisers, and still expecting these parts to stand up indefinitely without cracking under heavy alternations of thermal stress.

Metal Limitations in the Perfection of Motive Power

By Paul L. Irwin
Engineer of Tests
The Baldwin Locomotive Works
Philadelphia

Other parts of motive power, in addition to the boilers, tend to suffer from present commercial limitations in the manufacture of steels, castings and alloys of high and uniform quality, particularly in plates and forging billets. Mr. Irwin, speaking as a locomotive builder, presents some challenging statements to metal producers.

IN THE BRIEF TIME at my disposal, the large subject of metal limitations — even as limited to motive power — must be organized into main subdivisions. These may be *(a)* availability, *(b)* strength, *(c)* quality, *(d)* processing, and *(e)* cost. These will be now considered in order.

I. **Availability** — It seems reasonable to assume that all of the carbon and alloy steels in use before the war will be available post-war.

The greatly expanded production of magnesium and aluminum will certainly invite the use of these alloys. Their application in steam and diesel locomotives at the moment is limited to cab frames, aluminum bearings, stream-lining and other low-stressed parts. Their use in vital aircraft parts indicates that they will have increasing applications in motive power.

II. **Strength** — For highly stressed parts, and parts in which light weight is an important factor in reducing unbalanced forces, the high alloy steels will undoubtedly be used again. Such parts include main rods, side rods, axles, crank pins, pistons, piston rods, crossheads and boiler plate. In diesel locomotive engines, they would include crankshafts, connecting rods, connecting rod bolts, and fuel injection equipment.

Parts working at higher temperatures, such as superheater bolts, staybolts, and diesel valves will undoubtedly be improved by the use of better materials and the application of some of the new creep-resistant alloys now under active development. The power of internal combustion engines could be greatly increased if material for pistons capable of much higher operating temperatures could be obtained. The present materials for use

at such high temperatures are very difficult to machine. Recent metallurgical work on the gas turbine may, in all probability, be modified for such uses. One of these new alloys has the interesting property of *increased* ductility at high temperatures.

Failures of locomotive parts are almost invariably associated with fatigue cracks. Within reasonable limits we know that the endurance limit is associated with the tensile strength; therefore we should increase the tensile strength of the metal in the offending part, even though elongation and impact strength are somewhat reduced, provided due consideration is given to the effect of notches on the fatigue strength. (In other words, we heartily subscribe to H. W. Gillett's booklet* on "An Engineering Approach to the Selection, Evaluation and Specification of Metallic Materials" and recommend the book for reading and study by railroad men.) Careful consideration will undoubtedly be given to a gradual increase of tensile strength to provide better fatigue resistance wherever experience has shown a tendency toward fatigue failures.

III. **Quality** can best be considered under four heads: Castings, forgings, plate, and quality control.

The quality of steel castings, iron castings and non-ferrous castings has gone through an extremely rapid evolution during this war period. Primary credit should be given to the insistence of the armed services upon high quality, and reliance upon radiographic and magnetic inspection. Having learned (sometimes forcibly) the value of radiography in the production of sound castings, most plants having such equipment will undoubtedly continue to use it after the war.

The strength requirements of heavy locomotive forgings — such as axles, main rods, side rods, diesel crankshafts and camshafts — make it imperative that the steel be reasonably clean, free from non-metallic inclusions, residual pipe or any discontinuity that lends itself to the inception of fatigue cracks. This is apparently a difficult commercial requirement. The difficulty in obtaining metallurgically clean billets for large crankshafts, in fact, has forced some manufacturers into the use of cast steel or cast iron parts. Experience has shown that when a given foundry has developed the technique of producing a sound casting to a given pattern, all subsequent castings to that pattern will be uniformly sound. In the case of forgings, this situation does not hold because the forging manufacturer may have clean billets one week and dirty billets the next. (The word "dirty" is not just a figure of speech.) Our forgings for future motive power must be made of steel of greatly improved quality.

Plate material for weldments is also playing a very important part in the transportation industry. Welding technique has been markedly improved and important weldments are magnafluxed and X-rayed. However, a great deal of trouble has been encountered due to badly laminated plates which inevitably produce cracks and other defects in the weld. We have found this to be true in expensive, highly alloyed plates (S.A.E. 4140) as well as in the better grades of carbon steel plate. (For the benefit of the bright young metallurgists who are saying to themselves "Brother, you should specify aircraft quality steel", my parliamentary reply is "Unnecessary! All we intend to specify is normally clean steel comparable to the pre-war product, and we do not propose to pay any extras for that quality!") Improved welding techniques are nullified if the material contains serious defects. Serious epidemics of plate laminations are probably the result of pressure on the steel mills for astronomical tonnages, but every effort should be made by them to bring the quality up to pre-war standards or better, as soon as possible. As hinted by Mr. McBrian in his talk on boilers, one serious limitation in the design of steam locomotive boilers has been the prevalence of corrosion cracking that is associated with the higher strength steels. This limitation will be completely removed, based upon present evidence, when the all-welded boiler is the rule rather than the exception.

Control of Quality — In tomorrow's transportation, increased speed will be mandatory. Increased safety must also be insured. The record of the United States railroads, in this respect, is good; we have found that careful material inspection has reduced service failures of locomotive parts to a minimum. In my opinion, both increased speed and increased safety can be achieved by the continued diligent use of magnetic and radiographic inspection, and the intelligent application of known methods of avoiding fatigue failures. Fatigue tests and special types of dynamic testing, electric strain gages and brittle lacquer coatings have proved to be pre-requisite tools in the evolution of safe, light-weight mechanisms.

IV. **Processing** — Helical springs of large diameter wire have failed too frequently, due to surface decarburization and to wire-drawing marks. Such inferior material constitutes a serious limitation in the design of large helical

*Prepared for the War Metallurgy Committee, the National Research Council, and the War Production Board. Published by Penton Publishing Co., Cleveland 13, Ohio.

springs for locomotives and tenders. Valuable metallurgical advances and processing techniques, such as shot blasting for placing the surface under initial compression and correspondingly reducing the maximum of tensile stresses under recurring loads, will markedly improve the endurance limit but such advances are completely nullified if the processing of the bar stock and the heat treatment of the springs are not properly executed. Some of our eminent metallurgists have frequently criticized the railroad industry for failure to take advantage of new metallurgical and processing techniques, but experience has shown that *we must start with a basically sound material*, and the processing and heat treatment must be properly executed, before some of the newer developments can be safely applied.

V. **Cost** is always an economic limitation in the design of motive power. We are continually seeking to reduce the weight of many parts of the locomotive; a reduction in weight usually implies an increase in stress, and increased stress involves the use of comparatively expensive alloys and carefully controlled heat treatments. This obviously is costly, and frequently runs counter to the economic limitations mentioned.

Conclusions — Metal limitations in the perfection of motive power can be eliminated if the following steps are taken:

1. We strive to bring the quality of steel billets and plates up to the pre-war level or better.
2. We continue the use of magnetic, radiographic, fatigue and electronic testing where experience has shown them to be mandatory.
3. We improve the control of processing and of the actual heat treatment — adequate equipment for this is available.
4. We then utilize any of the new metallurgical and process developments that will be sufficiently beneficial to the part under consideration.

In the discussion of Mr. Irwin's talk, it was pointed out that the railroad man had greater confidence in carbon steels because of their general ruggedness and resistance to abuse by repairmen of rather low skill. One speaker said he would continue to favor them, since their quality was improving and since they had still to be used to their maximum advantage, and in best microstructural condition. Another pointed out that there was little specific information yet available as to the proper physical properties of alloy steels and the proper relationships — for example between elastic limit and ultimate strength, or between elongation, endurance limit, and notch-bar resistance — for specific applications such as a locomotive side rod. It is difficult to translate the experience of the automotive field to the use in railroad equipment, for the increase in size of the respective parts is so great that problems of heat treatment and mass effect arise.

Responding to a question as to his company's specifications for quality in the raw material, Mr. Irwin said that the primary test on a heavy forging such as a crankshaft is to deeply etch a disk cut from a prolong on each end. That is the only non-destructive test in use, other than magnaflux. Deep etch is susceptible to various interpretations, but the main idea is to decide whether the part is safe or not. Many large crankshafts had been rejected; one group of 19, rejected from a large shipment (the billets having originally come from several suppliers) were cut apart and studied internally, and there was only one of them about which rejection could be debated; 18 of the 19 revealed bad conditions of pipe and segregation which by the nature and shape of the part would introduce zones of weakness where the working stresses would be highest.

Improving the Railroad Axle

By O. J. Horger
In charge of Railway Engineering and Research
The Timken Roller Bearing Co.
Canton, Ohio

A DESIGN FORMULA for railroad car axles was developed by Reuleaux in 1896 and the fundamental geometry and dimensions established about 50 years ago have generally prevailed until recently. During this time, however, various metallurgical improvements were made in axle forgings, and this was fortunate, for as the years went by the railroads became conscious of the increased dynamic forces being imposed on axles as a result of changes in operating conditions, such as increased speeds.

The relative number of axle failures in road service was very small and, generally speaking, there was a known remedy for correcting these failures, except for those fatigue fractures which developed in the axle *under* the pressed-on wheel. Therefore this later type of fracture due to stress and fretting corrosion, so-called, is the one worthy of discussion now.

The solution to this problem obviously required fatigue tests. Ordinarily these are made — as is well known — on small, highly polished specimens of standard shape. In view of the difficulty in relating the properties of this small ideal specimen to the service of a large irregularly

In the fundamental work done by Dr. Horger and his associates on the fatigue strength of railroad axles, using full size axle and wheel combinations, an entirely new and damaging type of stress has been brought under control. A designer who relied on the fatigue strength of a plain 0.45% carbon axle steel, as determined by the small rotating specimen, would have felt comfortably safe with a maximum stress of about 30,000 psi, but cracks will start in the axle within the press fit at one-third that stress. And car axles are being continually worked at higher stresses in the modern severe operating conditions. The summarizer at this session (Mr. Trumbull) said that this work on axle and crank pin failures—exclusively due to fatigue and under conditions that railway engineers understand none too well—had been of great value, but should now be extended to driving axle design, since they are now subjected to stresses of intensity unknown in the days when bearings were exclusively of the bronze friction type.

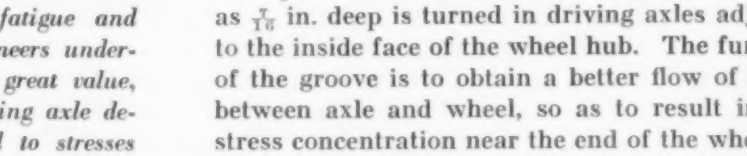
shaped object, the manner in which the investigation of axle failures proceeded was novel. There cannot be too much credit given to the decision of the Association of American Railroads (through its Axle Research Committee, of which W. I. Cantley is chairman) to make fatigue tests on full size car axles rather than scale size models. This project, including the fatigue testing of full size axles, was initiated in 1937 and is being continued seven days a week and 24 hr. a day.

Now what are the tangible results?

The design of the passenger car axle — that is, its shape — has been changed with no modification of material or heat treatment to obtain 60 to 80% increase in fatigue resistance at the wheel fit with an increase of only about 4% in weight. Also a heat treated tubular axle has been tested and approved by the Association of American Railroads, which is about 30% lighter in weight than the solid axle. Its better ratio of fatigue strength to weight is due to high residual compressive stresses induced in the outer surface. This axle is of steel with only about 0.35% carbon content without any added alloys, and its favorable fatigue strength to weight ratio is obtained by quenching from the outer surface only, preventing quenching water from entering the bore, and following with a low temperature draw. If a tubular axle were quenched from both outside and inside and tempered at the customary commercial temperature of about 1000° F., then it would have inferior fatigue resistance. (This use of the proper kind of residual stresses to improve the fatigue resistance of axles is also receiving increasing attention and application in aircraft and ordnance parts.)

Improvements in fatigue resistance, similar to those mentioned above for car axles, have also been determined for driving axles and crank pins. Again, the *shape* of the member has been modified to reduce the stress concentration occurring inside and near the end of the press fit. As an example, a circumferential relief groove as much as $\frac{1}{16}$ in. deep is turned in driving axles adjacent to the inside face of the wheel hub. The function of the groove is to obtain a better flow of stress between axle and wheel, so as to result in less stress concentration near the end of the wheel fit. This groove is rolled with a roller shape and pressure which is sufficient to plastically deform the surface layers of the groove. This operation of cold rolling increases the fatigue resistance of the metal at the bottom of the groove, and counteracts the detrimental influence that the round bottomed notch would have in inviting failure to occur in an otherwise smooth cylinder near the base of the groove. A large number of driving axles of this type have been placed in service and none have ever failed in the groove.

When axles or other machine members develop fatigue fractures it is common practice to make the entire part larger, instead of improving the design in the region of fracture. This erroneous procedure leads to increased rigidity, and under impact loading contributes to even higher stresses than would be obtained with a smaller, more flexible axle. Increased train speeds are considered to result in larger impact forces on axles than occur at low speed. Under these conditions it is desirable that the axle be as flexible as possible without developing failure, as well as be of light weight, so as to absorb this impact energy by a maximum of deflection and



Solid Car Axle Is Improved by Cold Rolling 7-In. Wheel Seat; Compressive Stress Is Induced in Tubular Axle's Surface by Quenching Outside Only

with a minimum of impact stress. In similar manner it can be explained how most designs of wheel centers with great lateral stiffness would increase the impact stresses in an axle from flange thrust over that obtained with a wheel with a more flexible center. It would be kind to the axle if a wheel center design could be provided of adequate strength but greater lateral flexibility than we have on most of the wheel centers in use today.

A number of railroads are cold rolling the wheel fit portion of driving axles. Rolling will about double the fatigue resistance of the axle against actually breaking off in the wheel fit, and there is no other known means of doubling the factor of safety against road failures at so small a cost. A combination of rolling and the relief groove has enabled some railroads to obtain greatly increased mileage, safely, from the axles. The present limited practice of machining out the very shallow fatigue cracks that may develop in the axle wheel fit made in this manner, and then re-rolling is one which could be safely extended in its use, for extensive research has given us a better knowledge of how the fatigue cracks initiate and then propagate in the wheel fit of an axle.

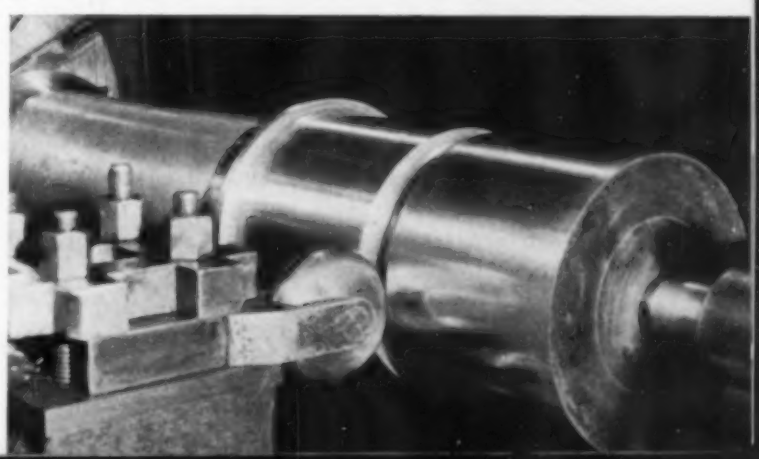
All railroad maintenance men have observed the patches of brown iron oxide found in particularly large amounts near the ends of the press fit. This is caused, in service, by a minute sliding action of the end portion of the hub bore on the axle surface, due to the alternate elongation and contraction of the axle fibers during its rotation. This minute and continuous rubbing of the wheel on the axle under bending stress results in one of the highest forms of stress concentration that is known, associated with a reduction of the fatigue strength of the steel through fretting or rubbing corrosion. Fatigue cracks initiate due to this rubbing corrosion at what appear to be very low axle bending stresses, as computed by ordinary formulae, but they generally will not propagate in depth at the same low stress value at which they initiate — a higher stress is usually required for propagation of the fatigue crack. Therefore the solution to the press fitted problem divides itself into two parts:

The first part deals with the *initiation* of the fatigue crack. During the life of many axles there are a large number of stress reversals of sufficiently low magnitude to initiate a fatigue crack. For example, it was found from fatigue tests of the old "black collar design" of car axle (as-forged, not heat treated after forging) that any nominal *calculated* bending stress in the wheel fit exceeding 9000 psi. would be likely to start a fatigue crack in the wheel fit. By a change in axle shape so as to mount the wheel on a raised seat in accordance with the design of the present A.A.R. passenger car axle, this 9000 psi. was increased to an allowable 12,000 psi., an improvement of 33%. If no significant change in shape of the wheel seat was made but surface residual compressive stresses were induced in the axle, as in the heat treated tubular axle, then this 9000 psi. would increase by 50% to 13,500 psi. It was also found that fatigue cracks would initiate in the wheel fit of the new design of normalized and tempered passenger car axle having a raised seat when the bending stress exceeded 9000 psi., or at a stress 3000 psi. lower than for the same design of axle in the as-forged condition.

All these stress values apply to car axles where the ratio of wheel seat diameter to the length of the wheel hub approaches unity; with driving axles and crank pins, however, these stress values are less favorable, possibly due to this ratio of diameter to length being much greater than unity. Here we find that fatigue cracks may initiate at stresses as low as about 5000 psi., nominal bending stress, as compared with 9000 psi. for the car axle. It is therefore apparent that, even if a 50% improvement in fatigue resistance could be obtained over the 5000 psi., the increased resistance would still be much below the stresses that could be regularly expected in service operation. Hence this problem of preventing fatigue cracks initiating in driving axles and crank pins is much more difficult of solution than for car axles.

The second part of this problem is concerned with the *propagation* of the fatigue crack which has initiated in the wheel fit as described above. In order to actually break off an as-forged axle in the wheel fit it generally requires a stress increment about 2000 to 7000 psi. above that required for *initiating* the fatigue crack; the actual stress depends on several factors of which the carbon content of the steel is one. For nor-

Inboard Railroad Axle Being Surface Rolled at Relief Groove. Wheel is pressed on outer end of axle so that inside hub face is flush with end of relief groove



malized and tempered axles this increment or margin of safety between a harmless superficial crack and a fatal growing crack is less than 1000 psi. The normalized and tempered condition gives a less favorable structure than the as-forged metal from the standpoint of fatigue resistance of car axle at the wheel fit. While this statement is contrary to generally accepted opinion, such findings have resulted from laboratory testing of many full-sized axles; it remains to be substantiated or found in error through the results of future road tests. On crank pins and possibly driving axles (normalized and tempered) the nominal stress must exceed 11,000 psi. to cause the incipient fatigue cracks to propagate to complete fracture.

By rolling the wheel seats of such members, or heat treating in a manner to leave high surface residual compressive stresses, a nominal bending stress of as much as 22,000 psi. is required to propagate initial cracks to a depth of about ¼ in. in 300,000 equivalent miles. A stress *greater* than 22,000 psi. would be required to propagate to complete fracture. Certainly this characteristic of greatly retarding crack propagation is of practical advantage from three angles: *(a)* It greatly increases the factor of safety against the axle breaking off in service; *(b)* mileage may be increased before it is necessary to examine the axles; *(c)* after 300,000 miles of service the fatigue cracks, if present, are shallow enough so they may generally be machined out by one of several practices and the axle returned to service with safety for another mileage period.

Brief mention must be made of the fact that the railroads are now locating, in good time, axles and other parts with very small fatigue cracks which would not have been detected by inferior methods of examination used in the past. The availability in later years of more refined methods of crack detection equipment, such as magnaflux, raises the question as to the value of data on cracked parts found now as compared with similar data on parts obtained previous to the use of better detection methods. Even now most railroads use the dry magnaflux method, whereas few use the wet method which is still more sensitive in locating flaws. Again, supersonic methods of inspection are being developed which claim still greater refinement and sensitivity in exposing some imperfections.

In summarization — Axles and crank pins may be improved by proper shape but if we are to obtain the maximum fatigue resistance, residual compressive stresses must also be present in the surface layers. These compressive stresses may be obtained in two ways:

1. By thermal means, such as proper type of quench, flame hardening or induction hardening. In these cases a sufficiently low drawing temperature must be used to avoid the release of the favorable initial surface stresses.

2. By some form of cold work or rolling.

These methods will about double the fatigue limit stress at which the axle or pin will break off within the press fit. (Shot peening, metal spraying and other methods of preparation have been found beneficial and still others are under constant investigation.)

While the values cited here generally apply to parts of plain carbon steel there are some limited data on alloy steels. Indications are that practices found beneficial for the carbon steel will also generally prove advantageous if alloy steels are used. In the meantime many of the results of this research are being applied in service for final correlation with the tests.

The Railroad Car Journal Bearing

By John R. Jackson
Engineer of Tests
Missouri Pacific Lines
St. Louis, Mo.

INTRODUCTORY to a discussion of the subject of the railroad car journal bearing and its improvement it will be well to review briefly its history and outline conditions under which railroad rolling stock has to operate.

It may be in order to recognize at the outset that the railroads have been and are being criticized for being slow in taking advantage of "progress" in the design and construction of journal bearings in other fields, and for being backward in extending the application of roller bearings.

I think it well to limit my discussion to the journal bearings under cars in interchange service — that is to say, cars which are operated under the rules of interchange as promulgated by the Association of American Railroads (A.A.R.). In normal times this covers practically all freight cars in service on the railroads of the country and — during the present war conditions — to large numbers of passenger cars as well.

The present-day standard A.A.R. journal box

assembly, of which the bearing is one part, is substantially the same as the assembly of 70 or more years ago. The parts have simply been increased in size with the adoption of the standard axle sizes. The bearing is and for many years has been a cast "bronze" back of copper-lead-tin alloy having a white metal (lead babbitt) lining ¼ in. thick soldered thereto; it carries the load through the crown and takes the lateral thrusts at the ends through the wedge and journal box. It is not a fitted bearing but must adapt itself to the diameter and contour of the journal on which it has to run, and must function with the component parts of the journal box, wheel and axle, and truck assembly of the running gear of the car, all parts being subject to relatively liberal manufacturing tolerances and wide wear limits before being condemnable, the tolerances and limits being based on long experience.

Under the Association of American Railroads' rules, periodic inspections of the journal box parts and renewal of bearings and other parts condemnable are provided for, standard parts being stored at all repair points throughout the country. Such work is performed by the handling line and the car owner is billed through the A.A.R. It can readily be appreciated that these time-honored practices are a powerful industrial reason for maintaining the status quo of any arrangement that is in no way hazardous. The railway mechanical forces at car repair and servicing points have evolved through the years, and are established through labor agreements which cannot be readily changed. These forces are not schooled in handling precision mechanical work but are experienced in handling relatively rough operations involved in the repairs to and maintenance of the present rolling equipment.

The present A.A.R. standard car journal bearings and associated parts in service and in stock on the railroads of the country represent a very large investment in material. To materially alter the present design of bearing would necessitate changes in other related parts of the journal box assembly and would truly constitute a major operation, result in confusion during the transition period, and would require a large expenditure on the part of the railroads. There would have to be a major reason and countervailing advantages for making any change that would not be interchangeable with the present equipment — that is, could not be easily replaced with present stock parts or an assembly thereof.

As a matter of fact and record, the over-all performance of the railroads in handling the unprecedented volume of business during the present war emergency has been accomplished with a remarkably low rate of train delays attributable to the design of the present conventional solid car journal bearing under freight and passenger equipment in interchange service. Any mechanical design, to be continued essentially without change for over 50 years on the railroads of this progressive country, and to stand up under the present overload, has proven itself to be reliable and efficient.

For these reasons, any changes in design of the car journal bearing will obviously have to be analyzed carefully from both the practical and economic viewpoints.

I do not mean to infer from the foregoing that the present design of railroad car journal bearing is perfect and that, therefore, there is no room for improvement. My purpose is to point out some of the factors which have to be considered in our problem of improving the railway car journal bearing during the years to come. The very desire to improve recognizes that the present arrangement is not perfect.

This leads us to the question as to what directions can be looked to for improvements in the present set-up. Three possibilities are open:

1. General adoption of anti-friction (mechanical) bearings.

2. Redesign of solid bearing and associated parts of the present journal box assembly without regard to interchangeability with present standard parts.

3. Refinement of design and manufacture of present bearing and associated parts, retaining interchangeability with present standard parts.

We will discuss these possibilities briefly.

Anti-Friction Bearing. There are those who advocate specifying anti-friction bearings for all new railroad equipment to be built from now on and progressively changing over all existing rolling equipment to anti-friction bearings during the post-war period. This is a large order. In my opinion it is not an impossibility but rather an improbability, because of the financial burden on the railroads this program would entail. I would also question the claims for anti-friction bearings in interchange service from a mechanical and performance standpoint.

The matter of application of anti-friction bearings to freight equipment is being studied by a committee under the A.A.R., and some progress has been made towards standardization of truck and box dimensions so that the bearings developed by the different anti-friction bearing manufacturers may be interchangeable.

Redesign of solid bearing and associated parts (without regard to interchangeability with present standard parts) includes a number of

things which might be done with a view to improving the present crown type, steeple backed, lined bearing. Among other possibilities are:

(a) Removing the standard thrust collars on the outer ends of axles, thus permitting the use of a sleeve or a semi-sleeve type of bearing.

(b) Eliminating the present conventional waste-pack used for journal lubrication, and providing an oil-tight journal box permitting flood or bath lubrication and thereby eliminating the possibility of a "waste grab" as a cause of lubrication disturbances in the present assembly.

(c) Redesigning the entire truck and journal box assembly for use on freight equipment cars, employing the pedestal type and separate journal box now generally used in passenger service.

Considerable progress has been made in this field of redesign as evidenced by the numbers of truck and journal box modifications which have been experimented with. Some service background has also been accumulated during the pre-war era.

Refinement of Design and manufacture of present bearing and associated parts, retaining interchangeability with present standard parts. Activities in this category have been considerable during the past 15 years, including a rather comprehensive research program under the direction of an A.A.R. Committee on Journal Bearing Development, under way since early in 1942. The results of the development and research in this field have made available many of the pertinent facts relating to both the possibilities and limitations of progress to be expected in this direction. There is little reason to believe that American railroads will be backward in assessing the facts as they are developed by this research committee and adopting those moves that will clearly be shown to increase safety and operating efficiency.

Some Effects of the Trend Toward Rolling Stock of Lighter Weight

By Stephen H. Badgett
Mechanical Engineer, Passenger Car Division
Pressed Steel Car Company, Inc.
Pittsburgh, Pa.

IN THE LAST DECADE, the passenger car particularly has been scrutinized with an eye toward improving appearance and reducing weight. There was a sound economic reason behind this — namely, to attract more passengers and to haul them cheaper. This is a widespread movement, far beyond the purchase of special "name-trains" of fixed consist.

As far as appearance and eye appeal go, adult travellers do not need to be reminded of the change, nor of the improvement in comfort. The exterior of passenger cars is not so different, although the sleek lines and broad windows of the newer equipment are immediately apparent. The interior decorations have been transformed from a rococo decoration of ingenious curves to the long, parallel lines in keeping with the shape of the structure. Harmonious color schemes have been carefully studied. Individual, reclining seats, amply cushioned, have replaced the less resilient and more crowded double seats in the older cars. "Body specialties" have increased greatly in number and importance.

Weight has been reduced by improved

★In this same session on Metals for Railroads Prof. W. M. Murray of Massachusetts Institute of Technology and president of the Society for Experimental Stress Analysis spoke on "Stress Analysis as a Means of Improving the Design of Railroad Rolling Stock". He pointed out that the final objective of stress analysis should be to produce the maximum economy consistent with safety. "Economy" involves, among many other things, the question of how much money may be available for the analysis, which may often be best answered by a joint effort such as the study already made of the A.A.R. standard box car. This, by the way, indicated that a safer car can be made that will carry 3.8 lb. of pay load per lb. of car and trucks, certainly a great improvement over the U. S. Railroad Administration's standard car of World War I, which can carry only 2.5 lb. of pay load per lb. of car and trucks. This new car is one, too, which can readily be built, an answer to the thought that if the stress analyst is given a free hand he will produce a highly desirable design that is so expensive to build it is out of the question.

As to the *methods* of stress analysis, Professor Murray said that the analytical methods of mathematicians are constantly being refined and improved. Furthermore an even more notable improvement has taken place in the experimental methods for determining stress distribution, such as the use of polarized light on transparent models and the various equipments for studying completed members and structures, such as electrical, mechanical and optical strain gages, X-rays, and "stress coatings".

Usually one considers that a stress analysis has been satisfactorily completed if knowledge of the peak stress has been determined in such a manner that service failures and accidents may be avoided. It would seem that in the future there would be another consideration that might be

Table I — General Trend in Steel Coach Weight

	1906 Coach	Late Twenties Coach	Modern Deluxe Coach
Weight of complete car	110,100	130,500	121,000
Weight of two trucks	36,500	33,600	39,000
Weight of complete body	73,600	96,900	82,000
Weight of body specialties	11,000	40,300	48,500
Weight of body without specialties	62,600	56,600	33,500
Body specialties in percentage of complete body	15%	42%	59%
Length of car	74½ ft.	79 ft.	85 ft.
Number of passengers	73	84	56

design, together with welding, high strength steels, and alloys of light metals — or a combination of the latter three. A scrutiny of three typical coaches of different eras and their components illustrates the general trend. See Table I.

Low alloy steel construction combined with an aluminum interior brought an abrupt decline in the weight of the complete car during the last 15 years. The weight of the two trucks shows some increase due to the addition of various ride-cushioning devices and specialties. The weight of complete body shows a decline from the late twenties but a breakdown indicates some interesting trends. For example, the weight of body without specialties shows the results of material development and design efforts in the weight of the combined structure and inside finish. Almost half the weight of the structure has been saved since 1906. However, the trend of body specialties is decidedly the opposite, having increased to over four times that of the 1906 coach.

Table II is on a per-passenger basis in order to compare the service offered by the railroads to their patrons in the three eras. The last column of Table II tabulates figures for the modern car of Table I with the interior rearranged to seat 84 passengers instead of 56. With reference to weights of complete car and complete body, this added column emphasizes the cost of the large lounge rooms and the spacious seating in existing deluxe coaches, with its decrease in total coach revenue and an increase in the weight hauled per passenger. This may also be an argument for further decreasing the complete car weight.

Omitting consideration of the 56-passenger coach for the present, the figure for weight of body specialties shows that the service per passenger in the form of comfort and safety attributable to the specialties has been considerably increased over the conditions existing from 1906 to the late '20's; it has been abruptly increased to over twice.

Items "Weight of body without specialties" accentuate the body weight reduction per passenger without penalizing the strength or safety of the structure. It is evident that the use of modern low alloy steels has considerably reduced the weight of the structure, but that the specialty weight has greatly increased and still tends in that direction. A broader use of the aluminum alloys in the deluxe coach, particularly in the structural members but not in the specialties, will reduce its weight to approximately 112,000 lb.

The increase in specialty weight may be attributed to two major causes — the increase in

Table II — Trend in Coach Weights per Passenger

	1906 Coach	Late Twenties Coach	Deluxe Coaches	
			Existing	Improved
Number of passengers	73	84	56	84
Weight of complete car	1510	1555	2160	1440
Weight of complete body	1010	1555	1465	975
Weight of body specialties	150	480	865	575
Weight of body without specialties	860	675	600	400

the inverse of this — that is, we would like to reduce weight by the elimination of unnecessary material. Many times excessive weight is carried due to the fact that little attention has been paid to the regions of the structure in which there are relatively small stresses. Where dynamic conditions are involved, as in all moving machinery or moving equipment, the inertia effect may be far more important than any static effect, and here is where the reduction of weight is of tremendous advantage.

Professor Murray laid especial emphasis on the desirability of producing a structure of essentially uniform stress so that as little material as possible is wasted. In some industries the cost of the excess material can be measured in relatively large numbers of dollars. This loss due to excess weight is not nearly as serious in the railroad industry as in the aircraft industry; the latter has been forced to carry on experimental stress analyses to a tremendous extent.

Finally, it must be remembered that no matter how good a stress analysis may be, it must be correlated with the resistance of materials which are to be used. Furthermore, a thorough study of failures should go on concurrently with any such analysis.

number, and the general lack of weight reduction in the individual specialty. I have gone into this second question of reducing the weight of specialties with various manufacturers. Usually, there were two solutions — a more efficient use of steel, or the use of the light metals, particularly aluminum. There was no hesitancy on the manufacturers' part to redesign around steel, but in some instances there was a marked hesitancy to use aluminum alloys. They would aver that the fabrication of aluminum was difficult and raised the price; that aluminum costs more, that it was not weldable, that aluminum castings tended toward porosity, that it corroded readily, and that it must be heat treated after fabrication.

Some of the objections are obviously due to lack of familiarity with the true facts, and can be overcome through a process of education by the aluminum suppliers. Other objections are valid and present a problem for some of us here today. *Cost* is always a watchword. It is a problem for the metallurgist and production engineer to produce a cheaper aluminum — not alone cheaper *ingot* aluminum, which is already with us, but correspondingly cheaper castings, extrusions and sheet. It is a metallurgical problem to produce an aluminum alloy that is comparable in weldability to steel. Corrosion resistance is also within the metallurgical field.

It would seem therefore that some of the major problems confronting aluminum, as far as its wider use by the railroad fraternity is concerned, are in the fields of education, metallurgy, and engineering, and should therefore be a challenge to some of us.

Body Design — The Association of American Railroads has published a specification covering the design of new passenger equipment cars. In this specification, there is a paragraph limiting to 1 in. the maximum vertical deflection of the car under a specified static end-buff. This is for all metals and is based on the distance between truck centers, with a recommendation of ½ to ¾ in. for steel construction having approximately 60-ft. truck centers. This requirement places a definite economic and weight handicap on the light metals and merits accurate stress analysis.

[Editor's Note: — Here the reader may refer to the footnote on pages 534 and 535. The summarizer of this session, Mr. Trumbull, pointed out that the A.A.R. box car is the only piece of rolling stock that has been adequately analyzed.]

In designing with the low alloy steels, much thinner sections are used today for structural members than in the era of plain structural steels. The designing engineer must now recognize and have a working knowledge of the elastic stability characteristics of members and sections of members. This also involves some complicated stress distribution in all-welded members. The structural side sheet of a girder construction is quite thin and is subject to shear buckling. Due to the rapid cooling, spot welds in the low alloy steels tend to form a hard zone around the weld, resulting in a lowered resistance to a tensile loading. This in combination with the tendency toward dynamic buckling of thin side sheets in service will result in tensile-fatigue failure of critical spot welds unless the designing engineer properly stiffens the side sheets.

We car builders are still having some trouble fabricating the low alloy steels due to their harder flow characteristics, liability to cracking under severe cold forming and, sometimes, defects apparently inherent in the steel's manufacture.

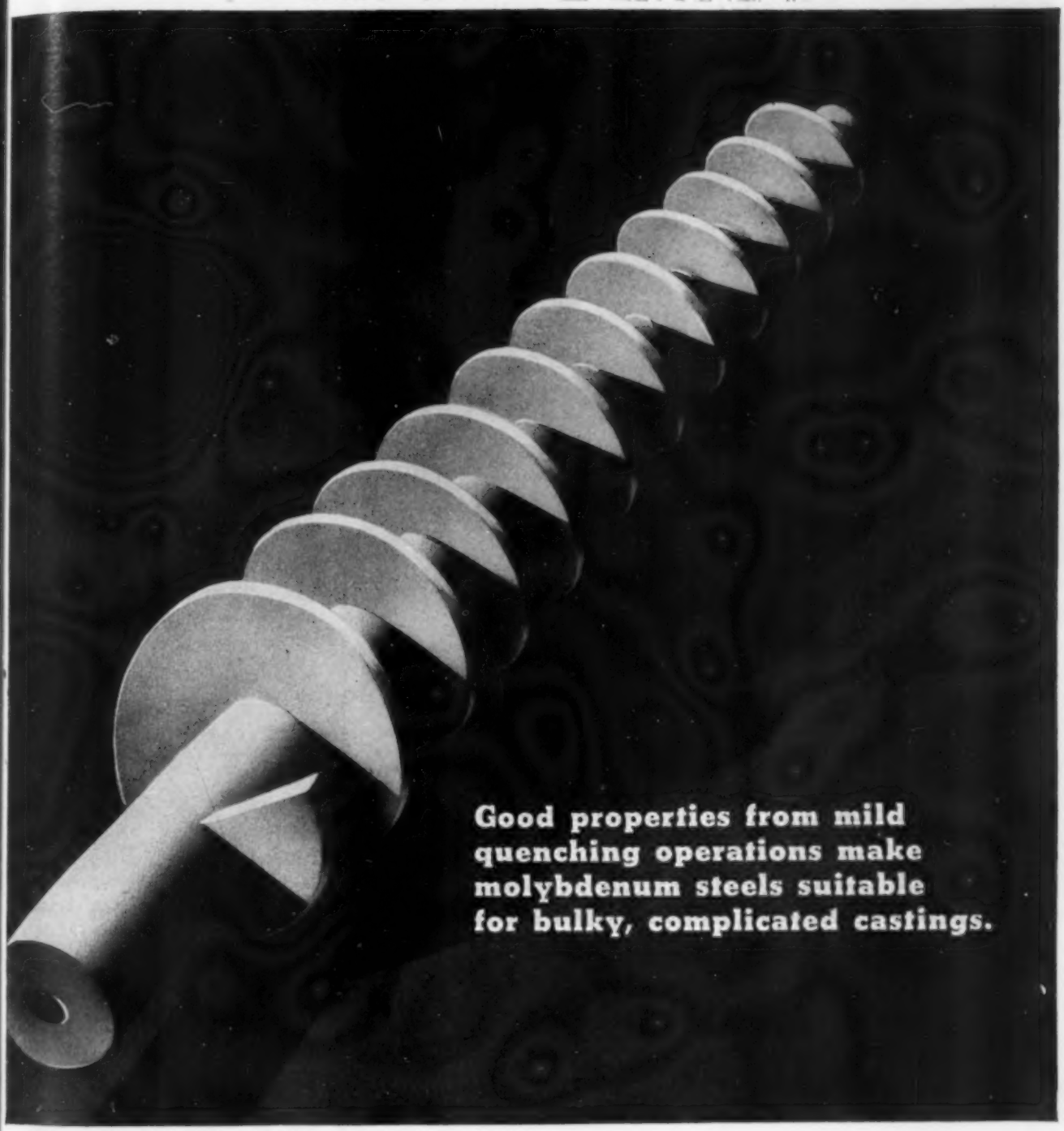
These problems present another challenge to the engineer and the metallurgist.

Relative Costs — The price of aluminum ranges from seven to ten times that of the low alloy steels on a per-pound basis. Even though the elastic modulus is roughly one-third that of steel, the structure does not require three times the material, and the lower weight of the aluminum alloys works to advantage. Considering the structural shell only, the proportionate total material costs in a passenger coach may drop to a 3-to-1 or a 2-to-1 ratio, depending on the size of the structure and the amount of steel present. The reflection of this ratio in the total cost, however, is markedly reduced by the addition of specialty prices, labor, and operating expenses. In proportion, the cost of a freight car would be influenced considerably more than that of a passenger car.

Economics — The economy resulting from the use of either aluminum or steel is not necessarily dependent upon the first cost or the weight saving involved. Other factors contribute largely. The savings in motive power and such recognized maintenance factors as ability to withstand fatigue, corrosion, and hard usage exert a considerable influence.

The car builder is faced with a reduction in the general size of individual freight car orders, and therefore he must operate efficiently from start to finish of an order. Uniform materials of construction that meet this normal requirement of the industry for economical fabrication and assembly must be available.

The faster and more efficient freight and passenger schedules of the future will counteract any tendency toward reversion to heavier structures, but the light weight cars must be well designed and economical to operate.



CLIMAX FURNISHES AUTHORITATIVE ENGINEERING DATA ON MOLYBDENUM APPLICATIONS.

ARMY E NAVY

MOLYBDIC OXIDE, BRIQUETTED OR CANNED • FERROMOLYBDENUM • "CALCIUM MOLYBDATE"

Climax Molybdenum Company

500 Fifth Avenue · New York City

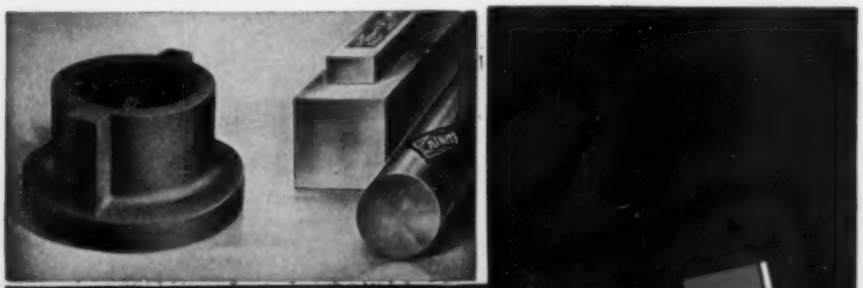
MOLY

PERSONALS

Appointments by Universal-Cyclops Steel Corp.: E. P. HARTER as sales representative in Western New York State; W. D. FISHER as special representative in Detroit; RICHARD H. DEXTER as sales representative in the State of Rhode Island; R. A. B. WILLIAMS as Pacific Coast representative.

R. L. HEATH, formerly chief metallurgist of the Allison Division of General Motors Corp., Indianapolis, Ind., has joined the Climax Molybdenum Co. as metallurgical engineer with headquarters in St. Louis, Mo.

H. J. LAWRENCE has been transferred from R. G. LeTourneau, Inc., Peoria plant, where he was inspection supervisor, to the LeTourneau plant of Vicksburg, Miss. in the capacity of Peoria representative.



KINITE

THE STEEL WITHOUT AN EQUAL

KINITE is in the high carbon chrome alloy tool steel air hardening class.

An analysis all of its own . . . .
Its characteristics:

1. Increases production.
2. Reduces grinding and retooling time.
3. Resists wear and abrasion.
4. Excellent machinability.
5. Minimum distortion.
6. Fine heat treatability.
7. Immune to cracking during heat treatment.
8. In bar stock or castings.

KINITE alloy air hardening steel offers an unusual combination of features never before found in a steel of this type.

Pamphlets on request.

EST. BOKER 1837

H. BOKER & CO., Inc.
101 DUANE ST. • NEW YORK

ALEXANDER GOBUS, chief metallurgist, and CHARLES DAVIDOFF, chemical engineer, have been elected vice-presidents of Sam Tour & Co., Inc., New York.

FRED J. TOBIAS, formerly production engineer for Sam Tour & Co., Inc., is now production manager for Powder Metallurgy, Inc., New York.

E. I. VALYI has resigned as vice-president of Sam Tour & Co., Inc., and is now president of A.R.D. Corp., New York.

H. F. MOORE has retired as professor of engineering materials at the University of Illinois, but will continue to engage in some special war work testing and some special studies in the fatigue of metals.

Transferred by American Manganese Steel Division of the American Brake Shoe & Foundry Co.: JOHN E. HOLTMAN, from Denver to St. Louis, Mo. as works manager.

ED JENNINGS is now employed at the Dominion Engineering Works, Ltd., Montreal, as roll metallurgist.

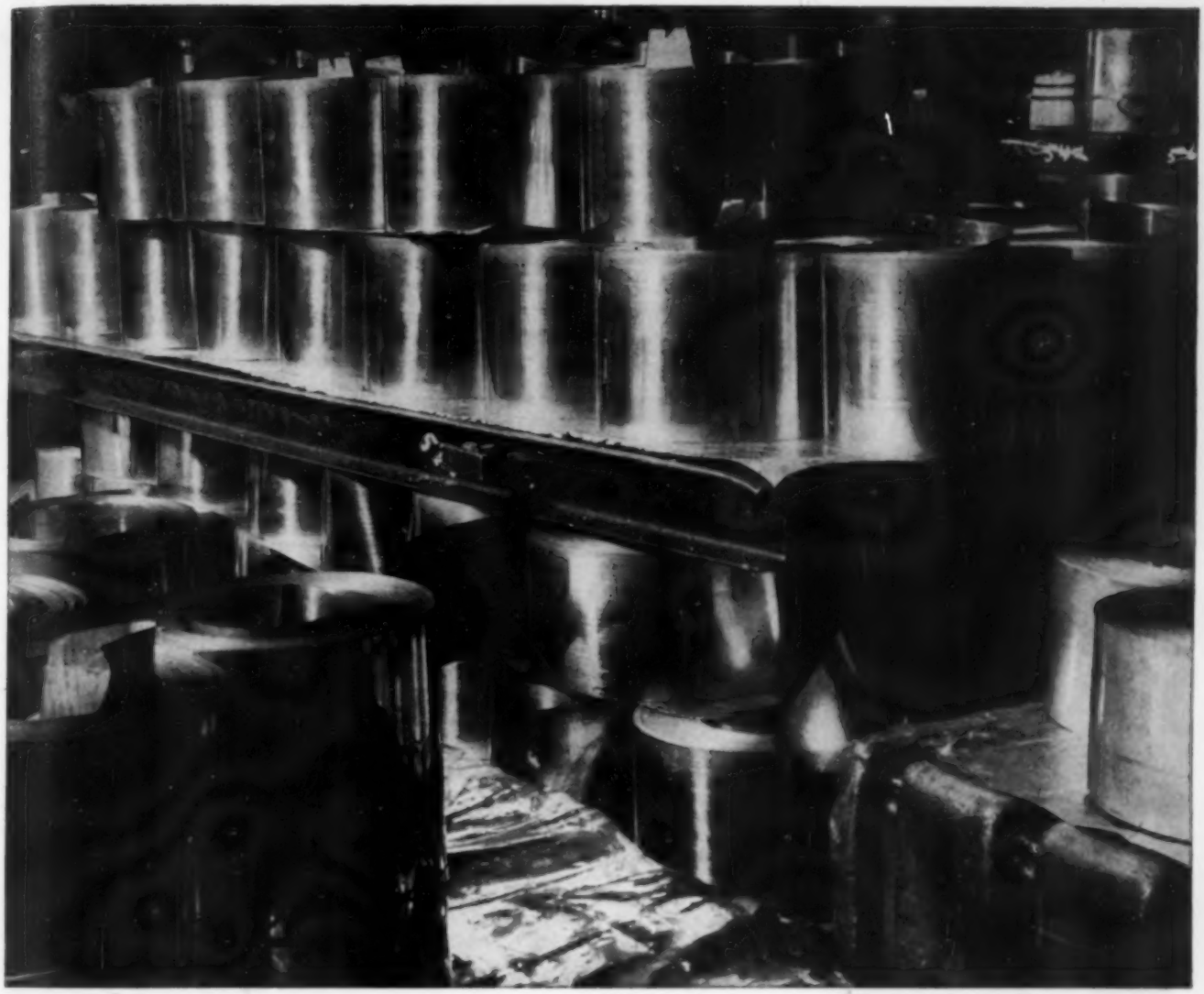
JOHN W. W. SULLIVAN, formerly chief of inspection, Cleveland Ordnance District, is now a member of the staff and consultant, Hill and Knowlton, New York.

P. C. BECK, formerly with the Aluminum Co. of America in Cleveland, is now chief metallurgist of the Castings Division of the Reynolds Metals Co.

R. W. WARING has resigned from the Sperry Gyroscope Co., Inc. to become associated with the Bridgeport Brass Co., Bridgeport, Conn., as chief engineer of the East Main Plant.

L. S. WILCOXON, formerly with Wright Aeronautical Corp., is now assistant plant engineer of the National Bronze & Aluminum Foundry Co. and the National Aluminum Cylinder Head Co.

L. L. WYMAN, who has been serving on the staff of the War Metallurgy Committee, is now back full time with General Electric Co., Schenectady, N. Y., as research metallurgist.



COPPER ON ITS WAY TO PERFECTION... BY REVERE

This picture shows coils of copper awaiting final processing in a Revere plant. It comes glistening from between the finishing rolls true to gauge. It is delivered to you in the form of sheet, strip or roll in the correct temper and finish as specified and in accurate dimensions. We have been rolling copper for 144 years, and being the oldest metal-working firm in the country, know how to do it right.

Today, Revere copper goes to war. It is a vital metal, available from Revere or its distributors on authorized C.M.P. orders.

Some day it will go to you freely for civilian metal work, for radiators, heat exchangers, stamped and spun parts, ducts, kettles and a thousand and one products. Copper is preferred for plant and home equipment and consumer goods because it is so easily cut, formed, worked and soldered; because of its high heat and electrical conductivity, its resistance to corrosion and the readiness with which it may be plated and tinned. In most applications it is so long-lasting as to be permanent.

When the day of reconversion comes, Revere will have few problems in its copper mills. We and Revere distributors in all parts of the country will supply you freely.

REVERE

COPPER AND BRASS INCORPORATED

Founded by Paul Revere in 1801

Executive Offices: 230 Park Ave., New York 17, N. Y.

PERSONALS

HARRY D. BUBB, JR. is now manager of the Jet Propulsion & Turbine Division of Thompson Aircraft Products Co., Cleveland.

T. H. STANCLIFF is now manager of the Rock Bit Division of the Security Engineering Co. of Whittier, Calif.

ADAM J. TEXTER has resigned from the Universal Cyclops Steel Corp., Bridgeville, Pa., and is now with the Chromium Mining & Smelting Corp., Ltd. of Sault Ste. Marie, Ont., as steel consultant for electric and openhearth furnace processes.

Elected to the board of directors of the Metal and Thermit Corp.: John B. Tinnon, vice-president in charge of sales, and WALTON S. SMITH, vice-president in charge of production.

Sentry Model YP Vertical HS Steel Hardening Furnace

STRAIGHT!
HARD!
CLEAN!

•

Use a **Sentry Vertical H. S. Steel Hardening Furnace** and **The Sentry Diamond Block Method** to assure . . .

• **STRAIGHTNESS**
• **HARDNESS**
• **CLEANLINESS**

Designed especially for Long and Large tools that are best hardened in a Vertical Suspended Position. Four sizes, with tool capacities up to 4¾″ Diameters and 36″ Lengths.

Built for Sentry Diamond Blocks with Sentry Operating Economy . . . Sentry Speed of Heating . . . Sentry Reliability

Bulletin 1023-4A Gives Details

The Sentry Company
FOXBORO, MASS., U. S. A.

Honored by the American Institute of Mining and Metallurgical Engineers: ROBERT F. MEHL, head of the department of metallurgical engineering, Carnegie Institue of Technology, awarded the James Douglas Gold Medal for distinguished achievement in non-ferrous metallurgy; EDWIN CHESTER WRIGHT, assistant to the president, National Tube Co., awarded the Robert W. Hunt Silver Medal and Certificate for his paper on "The Manufacture and Properties of Killed Bessemer Steel"; WILLIAM MARSH BALDWIN, JR., chief metallurgist, Euclid Case Plant, Chase Brass and Copper Co., Cleveland, the Institute of Metals Division Award for his paper on "Effect of Rolling and Annealing Upon the Crystallography, Metallography and Physical Properties of Copper Strip"; CARL GUSTAV HOGBERG, assistant to the chairman, Blast Furnace Committee, U. S. Steel Corp. of Delaware, the J. E. Johnson, Jr. Award for his contributions to the science and art of smelting iron ores in the blast furnace.

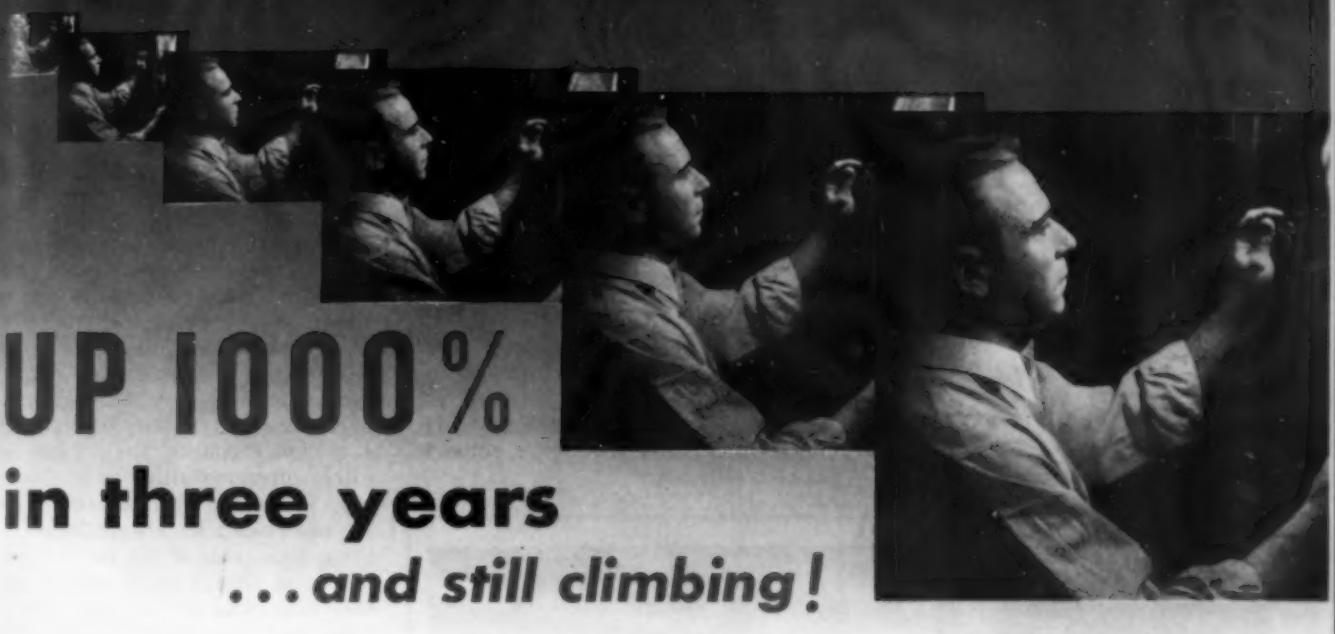
MARCUS A. GROSSMANN, director of research for Carnegie-Illinois Steel Corp., is the 1945 Howe Memorial Lecturer of the American Institute of Mining and Metallurgical Engineers; CHARLES SANBORN BARRETT, physicist, Metals Research Laboratory, Carnegie Institute of Technology, is the 1945 Institute of Metals Division Lecturer of the A.I.M.E.

LEROY E. FINK formerly of Denver, Colo., is now employed at Battelle Memorial Institute, Columbus, Ohio, as research engineer.

MAJOR ARTHUR E. INMAN, formerly executive officer, Sunflower Ordnance Works, Lawrence, Kansas, has been transferred to Office of Chief of Ordnance, Washington, D. C.

Promoted by A. F. Holden Co., BURTON R. PAYNE, from service engineer to field engineer for Southern California.

Transferred by Aluminum Co. of America: RUSSELL V. BOBB, from superintendent of tube plant, Lafayette Works, Ind., to superintendent of tube plant, Cresson Works, Pa.



UP 1000% in three years ...and still climbing!

RADIOGRAPHY'S PROMISE: extended horizons for your product... higher quality... lower costs.

A *fact everybody knows* . . . The war gave radiography the opportunity to demonstrate its ability to determine soundness or unsoundness of internal structure—nondestructively. *A fact not everybody knows* . . . Radiography has proved itself so widely to those who have had experience in using it that its growth has been spectacular—over 1000% in three years and it's still growing.

Let's look at some case histories. One manufacturer—faced with a probable 6-figure loss when *visual* inspection of his product showed hairline cracks in metal—called radiography to the rescue. Subsurface inspection—penetrating "x-ray" scrutiny—proved the "cracks" to be harmless surface "pleats" resulting from processing . . . not affecting structural strength. Thus, potential "scrap" went into effective use, hundreds of man-hours and machine-hours were salvaged.

Again, here's how radiography acted as a process "tool": Foundrymen told a motor maker that a new, highly efficient, lightweight, easily machined crankcase *couldn't be cast*. One foundryman took a chance, was troubled with shrinkage in the manifold exhaust. X-ray inspection of successive castings uncovered weaknesses. Seeing what was wrong, as the difficulties developed, made improvement possible. Today, this one progressive foundry is the sole supplier of all of the crankcases required.

And so it goes. More and more companies are finding radiography a great help in meeting today's rigid production schedules and high inspection standards. They know that the higher quality and lower cost resulting from radiography will be reflected in increased opportunities tomorrow. Eastman Kodak Company, X-ray Division, Rochester 4, N. Y.

PHOTO LAYOUT Cuts Template-Making Time 99%: Reproduces working drawings directly on metal, plastic, other sheet materials . . . with photographic speed and accuracy. Reproductions can be made by contact or projection . . . with unfailing precision . . . great savings in time.

RECORDAK Reduces Reference Time Two-Thirds: Saving dollars, time, space, weight, that's Recordak's contribution to industry . . . reducing bulky blueprints, drawings, papers to tiny microfilm. Photographically accurate full-size copies can be made quickly, and in quantity.

ULTRA-SPEED PHOTOGRAPHY "Magnifies" Time: Records motion too fast for the eye to follow . . . permitting study and analysis of moving mechanical parts, chemical reactions, air and liquid flow . . . smoothing production difficulties . . . saving man-hours, machine time, materials.

FUNCTIONAL PHOTOGRAPHY

Analyzes . . . Improves . . . Records . . . Reproduces

FUNCTIONAL PHOTOGRAPHY Serves All Industry: *Photo-Visuals* teach and sell, faster, with more lasting impressions. *Photomicrography* records microstructure of metal surfaces and effects of treatments. *Spectroscopy* analyzes complex substances, quantitatively and qualitatively, in a matter of minutes. *Electron Micrography* reveals detail beyond the limits of visible light, answers many hitherto unsolvable metallurgical problems. *Microradiography* probes into subsurface microstructures. *X-ray Diffraction* reveals the "invisible" by diffraction patterns, aids the search for better materials, processes. *Instrument Recording* provides a record on film for analysis and study of transient phenomena. *Stress Analysis* previews product performance.

Kodak

BRIDGE WIRE

(Continued from page 496)

Time extended to 40 months. Computed maximum stresses were from 90,000 psi. to 216,000 psi. ("Yield strengths" of the materials tested were 170,000 to 190,000 psi.)

No stress-corrosion cracks or failures occurred in any of the specimens exposed in distilled water although corrosive attack was very severe; it was of a localized nature in that rather large irregular areas were corroded more severely than some corresponding adjacent areas. The edges of these areas were very sharply defined, and within them the corroded surfaces were comparatively smooth. In some of these localized areas near the water line the diameter of the wire was reduced nearly 50%.

Likewise there were no stress-corrosion cracks or failures in 0.01-N ammonium sulphate up to 31 months, although there was equally severe corrosion.

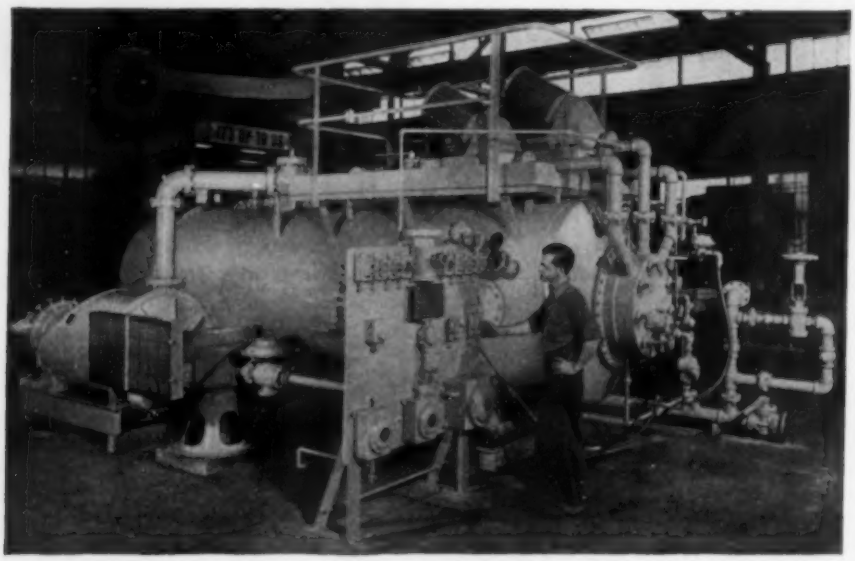
Stress-corrosion cracks, very similar in appearance to the service failures at Portsmouth, occurred in most of the specimens exposed to 0.01-N solutions of ammonium nitrate and of sodium nitrate. Most of the cracks were quite wide at the top and were filled with corrosion product. It was not readily apparent, therefore, whether they were transcrystalline or intercrystalline in these regions. In the innermost narrower parts, however, particularly after they had assumed a diagonal course, they were definitely intercrystalline in nature. In most cases the cracks produced in the laboratory tests were located on the convex side of the bowed specimens, as would be expected since this side was in tension. In two instances, however, cracks were also found on the concave, or compression, side of the bowed specimens. It is possible that these cracks had already occurred in service when this part of the wire was in tension and were present in the wire as received.

Only one of the 14 bowed specimens of Portsmouth wire exposed in the nitrate solutions did not fail, either by stress-corrosion or because of exceptionally severe localized pitting. This specimen, under a static stress of 90,000 psi., the lowest used, was immersed for 19 months in 0.01-N ammonium nitrate solution without failure. At the end of this period the specimen showed little evidence of corrosive attack in the central portion and only slight localized pitting near the water line.

A sample of heat treated Mt. Hope wire (stripped of its galvanizing) was stressed approximately to 183,000 psi. and developed numerous stress-corrosion cracks after 3½ months and failed after five months' exposure. This fracture was quite different from in cold drawn wire, being transverse all the way across the wire. The intercrystalline course of one of the cracks, particularly in its innermost part, is clearly revealed in the microstructure.

These tests strongly support the idea that service failures in the Portsmouth bridge wires were due to the effects of corrosion by dilute nitrate solutions combined with stresses much lower than would be produced merely by pulling the reeled wire out straight. An acceptable theory as to why certain solutions attack grain *boundaries* selectively has not yet been proposed nor does the author suggest one. Neither were the tests exten-

(Continued on page 544)



Specify INERTS or NITROGEN by KEMP

FOR PURGING — FOR BLANKETING — FOR PROCESSING

Kemp Inert Gas Producers and Kemp Nitrogen Generators are available in standard models with capacities ranging from 1000 to 100,000 cubic feet per hour—larger sizes and special models built to order.

Features on all models: Flexibility—gas production automatically responds to demand at any rate up to 100% of capacity, thus frequently eliminating need for gas-holders or accumulators to meet peak loads. Safety features include: electric ignition, safety-pilot, soft heads, and automatic shut-down in the event of (a) burner outage, (b) cooling water failure, (c) power failure, (d) fuel gas failure, and safety purging of unit on shut-down or before starting. Units may be furnished for either semi- or fully-automatic operation.

Safeguard against explosion hazards from flammable vapors or explosive dusts with low-cost Inerts or Nitrogen from Kemp Generators. Write for engineering data, recommendations and quotations.

Ask For Bulletin 901.3

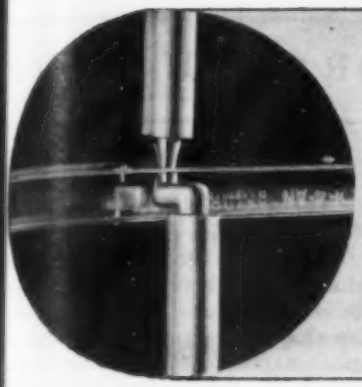
OTHER KEMP PRODUCTS

Nitrogen Generators • Inert Gas Producers
Atmos-Gas Producers • Immersion Heaters
Flame Arrestors for vapor lines, flares, etc.
The Industrial Carburetor for premixing gases
Submerged Combustion Burners
A complete line of Industrial Burners, and Fire Checks.

ARMY E NAVY

Address The C. M. Kemp Mfg. Co. 405 E. Oliver St., Baltimore-2, Maryland.

KEMP of BALTIMORE



DO'S *and* DON'TS
for
Resistance Welding Machines and Operations

Do's

1. Clean and tighten all electrical connections in the secondary circuit regularly.
2. Protect welding transformer slides, bearings and other parts from flash particles.
3. Keep the welder throat area to the minimum permissible dimensions.
4. Design welding fixtures and clamps with non-magnetic materials whenever possible.
5. Lubricate the resistance welding machine, motor, gears and slides at periodic intervals.
6. Clean all air or oil filters regularly.
7. Keep leather cup washers in air cylinders soft and pliable with light motor oil.
8. Calibrate all pressure applying mechanisms so that the exact welding pressure is always known.
9. Use proper capacity welding machine for the job.
10. Adjust the welding machine properly with the current initiating devices so that the current cycle is spaced midway in the pressure cycle.
11. Clean either chemically or mechanically all material to be welded that has dirty, scaly, oxidized or otherwise contaminated surfaces.
12. Provide suitable fixtures for holding the work in position prior to applying electrodes.
13. Provide rigidity in the welder arms and holders to prevent skidding of the electrodes, wheels or dies under pressure.

Don'ts

1. Don't permit flash particles to accumulate on the welding transformer.
2. Never use poorly maintained resistance welding equipment.
3. Do not use a long welder arm extension or a wide arm separation unless the parts to be welded necessitate it.
4. Avoid placing or fastening steel parts or fixtures in the throat area of the welding machine.
5. Shun lubricants which are not recommended by the welder manufacturer.
6. Don't use air operated machines when the oil bowl in the air line is empty.
7. Never permit oil or grease to come in contact with the transformer winding, electrical wires, or connections.
8. Never permit sliding pressure members to become too tight or jammed, since this will increase the frictional forces and inertia of the moving members.
9. Avoid using a low capacity welder for heavy welding jobs.
10. Do not allow welding current to be applied before full pressure is on work, or permit pressure release before the welding current is cut off.
11. Never weld unclean metals, scaly stock, or metals with poor surface condition.
12. Don't use welding tips, wheels or dies to form or shape parts in the welder.
13. Never apply the electrodes to the work with a hard impact or hammer blow.

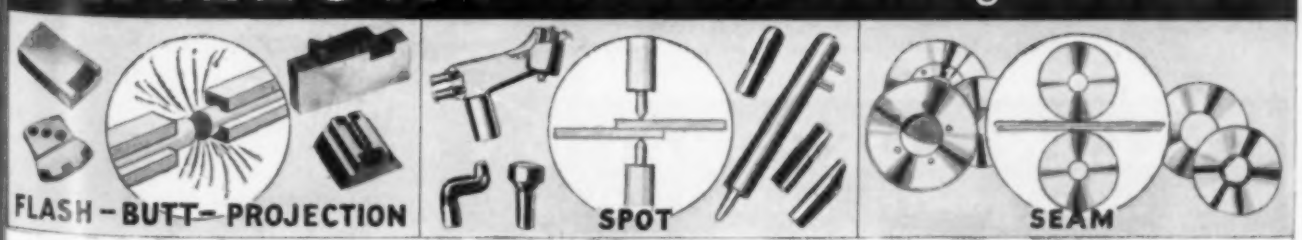
DO increase production by using Mallory Standard Resistance Welding Electrodes —spot welding tips and holders. Consult us for seam welding wheels, flash, butt and projection welding dies for your particular application. Write for your copy of the electrode catalog and the Mallory Resistance Welding Data Book sent gratis to resistance welding engineers when requested on company letterhead.

One of a series—the entire series mailed at your request.

P. R. MALLORY & CO., Inc., INDIANAPOLIS 6, INDIANA

P. R. MALLORY & CO. Inc

MALLORY *Standard* Resistance Welding Electrodes



VULCAN Furnaces

For Fast, Accurate Heating and Heat Treating Operations

The battery of three Car Hearth Furnaces illustrated above is typical of all VULCAN installations in advanced design, efficient, high-speed heat treatment, and economical operation and maintenance. Used for handling miscellaneous forgings and weldments, they are oil fired, with complete automatic control in two zones. Temperature uniformity of 10° plus or minus is readily maintained. Cars and doors are motor operated. Doors are equipped with air operated clamps for sealing.

Furnace No. 1, in foreground, is direct fired and used for annealing and normalizing at maximum temperature of 1700°.

Furnaces No. 2 and No. 3 are convection heated and are used for normalizing at temperatures up to 1250°. Each is equipped with two high temperature fans.

An imposing list of installations demonstrates the important part allotted to VULCAN Furnaces in the Nation's war effort, and of the high measure of success attending it.

Although each VULCAN installation is engineered to meet specific requirements, the cost is generally no greater than for standardized equipment. Let us quote on your requirements.

VULCAN CORPORATION
1796 CHERRY STREET, PHILADELPHIA, PA.

BRIDGE WIRE

(Starts on page 496)

sive enough to determine whether or not there is a lower limit of imposed static stress below which failure of the bridge wire samples would not occur. At stresses lower than the yield strength the time of exposure necessary to cause failure seemed to increase considerably. The lowest stress at which stress-corrosion cracks were obtained within a reasonable length of time was 100,000 psi. It is possible, however, that exposure for longer periods, comparable to those which might occur in service, would cause failure at lower stresses.

It should be pointed out that the stresses mentioned are the nominal static stresses imposed by bending the wire. Because of the difficulty in evaluating the residual stress in a curved wire of small diameter, its possible presence was not taken into account, and therefore the imposed stress may not be the true stress. It has been suggested that "acid embrittlement" has some relationship to stress corrosion, and that the reason why it is so dangerous to immerse heat treated wire in acidified cleaners (whereas cold drawn wire is relatively immune) is that the very surface of heat treated wire is in tension. As a matter of fact, cold drawing operations usually result in residual stresses whose distribution is such that the surface of the drawn wire is in tension. As the Portsmouth wire was not heated after the last pass through the cold drawing die, it is probable that the convex side of the bowed specimens of this material was under some residual tensional stress in addition to the applied stress. In these cases the actual stress, therefore, might be considerably higher than the nominal applied stress. The surface of heat treated wires might be either in tension or compression, depending on the rate of cooling. As the heat treated Mt. Hope wire was both tempered and hot dip galvanized, it would be expected that any residual stress resulting from quenching would be largely relieved. Similarly, hot dip galvanizing would act as a stress relieving treatment for the cold drawn Mt. Hope wire which did not fail in the nitrate solutions. In these cases it is probable, therefore, that the applied stress was very nearly the true stress.

LEAD FOIL LAPS

(Continued from page 508)

of particle size and must have the proper consistency. Most of our polishing has been done with a suspension having a range in particle settling rate of from 1 in. in 1 min. to 1 in. in 10 min. It is well to eliminate the finer particles as well as those coarser than the desired size range. An abrasive of the proper consistency can be obtained by decanting the refined settled suspension until the volume of supernatant liquid is equal to or twice the volume of the cake.

2. The area to be polished must be left flat by the preceding operation, since only the area which touches the foil will be polished.

3. Each area of the lead surface must not be used beyond the point of "saturation" with abrasive particles. The lead becomes light gray in color after a few strokes and darkens as the polishing continues. If the specimen is polished in one area after the lead surface has become darkened, the type of cutting action changes. Further polishing may give a thin distorted layer at the surface which cannot easily be removed in final polishing, and the depth of the scratches will become uneven.

4. At the first sign of scratching foil should be replaced with a fresh sheet. If the depth of scratching becomes uneven, the polishing can be continued on a fresh area of the sheet. (This is a considerable advantage over the cast lead lap, which must be remachined for comparable results.)

Although the process has been used at Watertown principally as an intermediate step between 000 metallographic paper and the final polishing operation, surface-ground specimens have occasionally been polished directly on lead, using "5 to 10-min." alumina suspension. (Particle sizes of abrasive which have been used successfully in the various steps range from those settling at 1 in. in 30 sec. to 1 in. in 2 min., to those settling at 1 in. in 30 min. to 1 in. in 50 min.) If desired the lead step with 5 to 10-min. abrasive may be followed by polishing with the same suspension on a freshly scraped rotating wax wheel, using a little alcohol as a wetting agent, so as to leave a minimum of polishing to be done in the final polishing operation. Although not essential, this has been found advantageous for some purposes. (An alternative to the wax method is a second lead operation using a finer suspension: 1 in. in 20 min. to 1 in. in 40 min. This two-stage process has been used quite successfully in obtaining an extremely flat, scratch-free, distortion-free polish, almost completely eliminating any rounding at crack edges.)

The final polishing process preferred for finishing specimens prepared on lead foil uses a water suspension of Gamal alumina on Gamal cloth, using alcohol free of abrasive particles as a moistening agent. (See the article by Anton L. Schaeffler on "Rapid Hand Polishing of Micro Specimens" in *Metal Progress* for August 1944, for a description of "Gamal on Gamal" process.) This method is more rapid than most other final polishing techniques, and lessens any susceptibility to pitting. It has been found that the time required for this final polishing operation is seldom greater than 1 min. (J. B. COHEN, Associate Metallurgist, and J. H. MAKER, Assistant Metallurgist, Watertown Arsenal)

CONTINUOUSLY UNIFORM ACTIVITY

. . . with minimum amounts of new added . . . .

CHAR CARBURIZERS

CHAR PRODUCTS COMPANY

MERCHANTS BANK BUILDING INDIANAPOLIS

COLUMBIA MOTOR GENERATORS

for Electroplating and other Electrolytic Processes

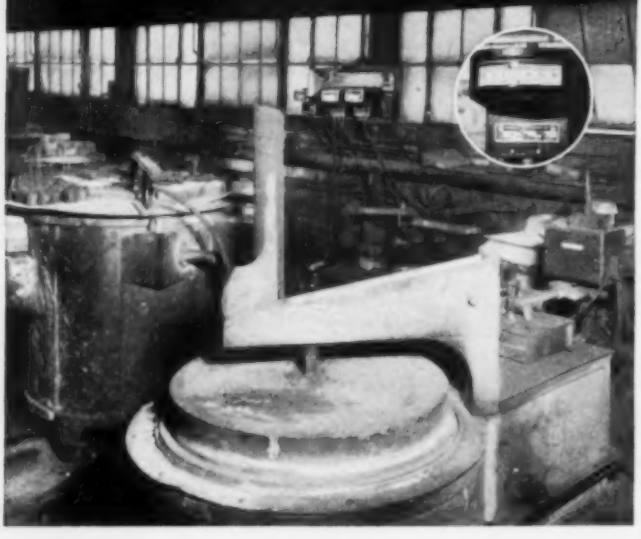
Columbia Generators embody every feature essential for dependable, 24-hour operation. They are built for electroplating service in sizes of 6 to 20 volts, 500 to 20,000 amperes, for anodic treatment of aluminum in sizes of 40, 50, and 60 volts, 500 to 3,000 amperes. Columbia Generators for other electrolytic processes range from ½ to 250 KW, 100 to 40,000 amperes, 6 to 60 volts.

Prompt shipment can be made on any type and size. Write for full information.

COLUMBIA ELECTRIC MFG. CO.

4519 Hamilton Ave., N. E. - Cleveland 14, Ohio

23 Capacitrols for Geo. H. Porter



Featuring furnaces up to 22'-6" long, Geo. H. Porter Steel Treating Company, Cleveland, Ohio, is equipped to handle heat treating of a wide range of work, with tool steel a specialty.

In addition to standard types, a number of special furnaces are in operation—developed by Lee Wilson in collaboration with engineers of the company.

To meet the requirements of highest dependability in furnace temperature control, 23 Wheelco Capacitrols (both surface and Universal types) have been installed.

IN ALL INDUSTRIES requiring temperature control, Wheelco provides the finest obtainable instruments for protecting big investments in materials and equipment.

Wheelco Universal type Capacitrol, providing any combination of indicating control or signalling. Ask for Bulletin D2-4.

WHEELCO CONTROLS

A complete line, including Flame-o-trol combustion safeguards . . . Capacitrol pyrometer controllers . . . Indicating pyrometers . . . Proportioning controls . . . Program controls . . . and a wide range of accessories.

WHEELCO INSTRUMENTS COMPANY

835 W. Harrison St. Chicago 7, Ill.

WHEELCO

Made in 3 Types and 9 Sizes 200 lbs. to 5,000 lbs.

CHAMBERSBURG PNEUMATIC FORGING HAMMER *(Motor Driven)*

Self-contained motor compressor and hammer in one unit. Anti-friction bearings, clean, low-center-of-gravity construction, improved long ram guides are valuable features. Its greater forging output is due to its heavier anvil construction, higher impact speeds and greater rapidity of blows.

Further details in Bulletin No. 1275

CHAMBERSBURG ENGINEERING CO., CHAMBERSBURG, PA.

CHAMBERSBURG

HAMMERS • PRESSES • CECOSTAMPS

A.I.S.I. **HY-TEN** S.A.E.

N.E.

Alloy Steels for Victory

Scientifically selected to conserve critical alloys and meet the requirements of the AIRCRAFT, ORDNANCE, and MACHINE TOOL industries.

Complete "EARMARKED" stocks of Aircraft alloy steels at Buffalo and Detroit.

WHEELOCK, LOVEJOY & CO., INC.

138 Sidney Street, Cambridge 39, Mass.

CLEVELAND 14, - CHICAGO 23, - NEWARK 5, - DETROIT 3, BUFFALO 10, - CINCINNATI 32

POT TESTS

(Continued from page 510)

(b) If the acid reacts slowly to brown-black color, the material either ordinary steel, low alloy el or cast iron.

(c) If no reaction occurs, the terial is chromium-iron stainless rritic or martensitic alloy).

Procedure B; for Slightly Magnetic Materials

Place a drop of concentrated tric acid on a cleaned area.

(a) If the acid reacts to a green- e color, monel is indicated.

(b) After reaction has ceased, d one or two drops of water, merse an iron nail or steel knife ade in the drop and in contact th the test sample. If the nail or ife blade becomes coated with pper, or if a copper deposit pears on the material being ted, the latter is monel.

(c) If no reaction occurs, the terial is heavily cold-worked romium-nickel stainless steel nstenitic alloy, with some mag- tic martensite formed by the cold ork).

Procedure C; for Non-Magnetic Materials

Place a drop of concentrated nitric acid on a cleaned area.

(a) If the acid reacts rapidly to a blue-green color, the material is nickel silver or copper-nickel.

(b) If the acid reacts to a green-blue color, the material is "K" monel or "S" monel. The form of the material will assist in identification since "K" monel is never cast and "S" monel never wrought.

(c) If the acid reacts to a brown-black color, the material is Ni-resist.

(d) If no reaction occurs, the material may be either inconel or austenitic chromium-nickel stainless steel with or without molybdenum. To distinguish between these two: Place on the sample a few drops of a solution containing 10 g. of cupric chloride ($CuCl_2 \cdot 2H_2O$) in 100 cc. of concentrated hydrochloric acid and allow it to stand for 2 min. Then slowly add a few drops of water, one drop at a time, and finally wash off the solution. If a copper-colored spot remains the material is chromium-nickel stainless steel with or without molybdenum; if an uncolored etched spot remains, the material is inconel. In case of doubt confirm by placing 1 drop of concentrated hydrochloric acid on a clean surface and allow it to react for 1 min. Then add 1 drop of an acid ferricyanide solution containing 1% by weight of potassium ferricyanide, $[K_3Fe(CN)_6]$ and 10% by weight of sulphuric acid. If a dark blue color appears quickly, the material is chromium-nickel stainless steel with or without molybdenum; if no color develops it is inconel.

(e) A distinction may be made between types 316 and 317 stainless steel, which contain molybdenum, and the plain chromium-nickel types 302 and 304, by immersing the alloy in a water solution containing 75% by weight of orthophosphoric acid (H_3PO_4) and 1 to 30 g. per liter of common salt (NaCl) at 140 to 200° F. If the stainless steel does not contain molybdenum (types 302 and 304) bubbles of hydrogen will begin to form within 30 sec. If the alloy contains molybdenum (types 316 and 317) bubbles will not form. The quantity of sodium chloride and the testing temperature are not critical within the limits indicated. (W. A. MUDGE, Development & Research Division, International Nickel Co.)

Alloy Constructional Steels

by H. J. French

In Charge of Alloy Steel and Iron Development International Nickel Co.

MR. FRENCH's lectures on "Alloy Constructional Steels" were so well received at the recent Western Metal Congress that they were reproduced in book form.

This 275-page book covers alloys in commercial steels—why alloy steels are used—selection of alloy steels—typical commercial uses—commercial steels and manufacturing variables—high alloy steels—wear—how alloying elements may affect corrosion of steels—processing and special treatments.

In a time when much of our steel is being used for construction, the valuable information contained in this book is particularly important and timely. Order your copy today.

275 pages . . . 95 illustrations . . . 6" x 9" . . . Cloth binding

$4.00

Published by

American Society for Metals

7301 Euclid Avenue Cleveland 3, Ohio

This VALUABLE BOOK GLADLY sent

This handbook is written for you . . . to give you, in the simplest form, the answers to questions and where and how to use Phosphor Bronze and how to choose the alloy best for your purpose. You'll find it authoritative, complete, a great help in your work. And, your request for a copy entails absolutely no obligation!

Tear-off coupon

THE PHOSPHOR BRONZE SMELTING COMPANY
2212 Washington Ave., Phildelphia, Pa.

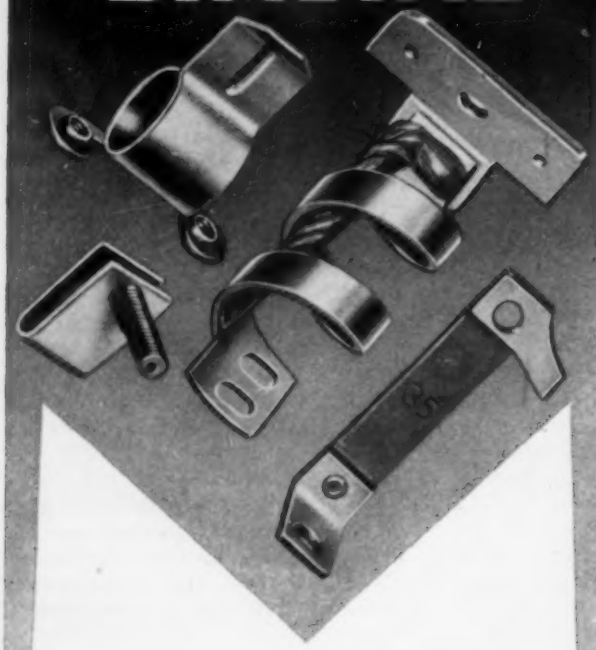
Please send me a copy of your Technical Data Book

NAME TITLE

FIRM

ADDRESS

CHACE *Thermostatic* BIMETAL



35 types of Chace Thermostatic Bimetals in sheets, strips, shapes to specifications, and sub-assemblies are being supplied to manufacturers for use in vital instruments and controls for planes, ships, tanks and trucks.

Chace is always ready and anxious to cooperate with you on any problems pertaining to actuating elements for temperature responsive devices.

W.M. CHACE CO.
Manufacturers of
Thermostatic Bimetals and Special Alloys
1626 BEARD AVE • DETROIT 9, MICH.

MANAGEMENT COUNSEL

JOSEPH C. LEWIS
President

Mr. Lewis has been active in management and industrial engineering fields for the past twenty years. He was formerly president and general manager of a nationally known electrical products manufacturing company, general manager of a leading home appliance manufacturing organization and vice president and plant manager of a large stove and furnace manufacturing company. He was associated with an established consulting management engineering firm as executive vice president. Mr. Lewis is the founder of Associated Engineers, Inc.

- Industrial Engineering
- Methods
- Work Standards and Costs
- Job Evaluation
- Wage Incentive
- Architecture
- Structural Engineering
- Civil Engineering

ASSOCIATED ENGINEERS, Inc.
230 East Berry Street — Fort Wayne 2, Indiana

More or Less CAN MAKE A BIG DIFFERENCE

Let an accurate Dillon Dynamometer handle the various weighing problems in your shop. Ideal for quick spot checking at inventory time or when production materials must be weighed. Measures only 8¼"x6¼"x3". 9 capacities: 0-500 lbs. up to 0-20,000 lbs. — all reasonably priced. Write for technically illustrated catalog.

W.C. DILLON & CO., INC. 5420 WEST HARRISON ST. CHICAGO 44, ILL. U. S. A.

Accurate • Dependable